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AQUILA REMOTELY PILOTED VEHICLE SYSTEM TECHNOLOGY DEMONSTRATOR (RPV-STD) PROGRAM

Volume III - Field Test Program

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APPLIED TECHNOLOGY LABORATORY
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Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report provides the results of the program of design, fabrication, integration and test of the AQUILA (XMQM-105) RPV System Technology Demonstrator preparatory to delivery of this system to the US Army for engineering design test and force development test and experimentation. System performance presented herein supports the conclusion that an RPV system can provide capabilities for battlefield reconnaissance, target acquisition, and target designation. However, the reader is advised that system tests reported herein were developmental in nature and the results are limited. Complete performance of the AQUILA demonstrator system can be obtained only through an appreciation of the results in this report and the results of the Army's engineering design and force development tests. Engineering design tests were conducted by the US Army Electronic Proving Ground with results published in *Final Report/Engineering Design Test - Government (EDT-G) of Remotely Piloted Vehicle - System Technology Demonstrator*, TECOM Project No. 6-AI-53E-RPV-005, June 1978.* Force Development tests were conducted by the US Army Field Artillery Board and published in *Force Development Testing and Experimentation of Remotely Piloted Vehicle System/Final Report*, TRADOC Project No. 6-AI-53E-RPV-003, 6 January 1978.**

Mr. Gary N. Smith of the Aeronautical Systems Division served as the Contracting Officer's Technical Representative for the RPV System Technology Demonstrator Program.

Report Control

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System refinement and demonstration, and final Army crew training was accomplished at Fort Huachuca, Arizona, in 1976. The program required 28 flights and demonstrated major system functions prior to Army flight mission exercises to assess the system. The system proved most effective for surveillance and targeting.

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SUMMARY

The Aquila field test program progressed over a period of 19 months, commencing on 1 December 1975, at the Crows Landing Naval Auxiliary Landing Field near Patterson, California, and concluded on 10 July 1977 at Fort Huachuca, Arizona. The initial flights at Crows Landing used partially complete software, partially tested Ground Control Station (GCS), and partially tested RPV autopilot components. These flights were, therefore, also "debugging" as well as "proofing" flights. The LMSC field crew was made up of both test and engineering personnel, with professional engineers and technicians working side by side troubleshooting and modifying hardware. Once basic system performance elements such as RPV airworthiness, data-link lockup, autopilot responses, and radio-control operation were verified, the team and hardware were moved to Fort Huachuca, Arizona. Operations began there early in January 1976 and proceeded with only one interruption of three months' duration (from May 1976 to August 1976). The flight test program progressed slowly at first because of several aircraft losses and the resultant investigations and corrective actions. The flight failures were random in nature and chiefly nonrelated. It seemed that as each new feature of the GCS-RPV interface was tested, problems were uncovered. Slowly, critical system elements were verified one by one; however, the hook-arresting/line horizontal retrieval system concept continued to be at the root of most of the serious flight problems. From January through April 1976, seven flights were made. Progress was made toward evaluation of radio control, manual and waypoint guidance, data-link characteristics, autopilot performance, RPV flight characteristics, RPV-GCS operational integration, expansion of software routines, launcher operation, development of operational and checkout procedures, and LMSC operational crew training. However, six RPV losses occurred. The Army directed LMSC to suspend the flight

test program and enter into an in-depth system reliability improvement redesign program, which involved hardware, software, and operational procedures.

After three months, the field crew returned to Fort Huachuca with hardware modification kits, software changes, and procedural changes. A parachute system was added to each RPV as a backup to minimize the loss of expensive RPV hardware. The flight test program plan was revised to provide a new rationale:

- Defined objectives for each flight that would fit into an overall "building block" logic relating each flight to subsequent flights
- Eliminated reliance on a 100-percent program success approach by providing repetitive and/or redundant flight objectives, utilizing the Otter aircraft and RPVs.
- Provided contingency flights to cover changes in scope and circumstances preventing accomplishment of test objectives

The flight validation and demonstration program was restructured into two phases:

- Phase A. Validation of RPV-GCS performance requirements, launcher operation, retrieval system operation, operational procedures, checkout procedures, and U.S. Army test team certification
- Phase B. Sensor mission validation.

On 13 September 1976, flight testing was resumed (Flight 14) with the RPV hook assembly and arrester-line horizontal net configuration. That retrieval attempt was unsuccessful and resulted in adoption of the vertical ribbon barrier system for all subsequent flights. The Phase A flight validation and demonstration program then proceeded and was completed on 23 February 1977 with Flight 37. Several Otter aircraft flights were integrated into this test series, which served as system check flights and training opportunities. Every design feature of the Aquila system, with the exception of sensor functions, was tested and evaluated.

As a result of flight test anomalies, data reduction, operational difficulties, etc., a "B" modification improvement program was defined and approved by the U.S. Army. Product improvements touched every major element of the Aquila system, including the launcher, retrieval system, RPVs, ground control station and software. During March 1977, the changes were incorporated into the hardware and software. RPVs 012 and 013, which had been repeatedly flown during Phase A, were modified with some of the more critical "B" modifications. Flights 38 through 41 were check flights of these two RPVs for verification of the improvements made in the entire system. Each RPV was flown successfully two times, and performance data were gathered.

While the "B" modifications were being incorporated and flight tested on modified "A" model RPVs, the second series of deliverable RPVs – i.e., RPV 014 and up – were being fabricated and acceptance tested at Sunnyvale. These were called the "B" model aircraft. Ten "B" model RPVs were constructed (RPVs 014 through 023). Of this quantity, four were flight tested by LMSC with the five types of sensors.

The Phase B flight demonstration and validation program required 2 months for completion. Integrated into this test series were 10 training-exercise/dry-run flights with sensors installed in the Otter aircraft. This sensor training was held for the benefit of LMSC, as well as U.S. Army operators. Twenty-four "B" model RPV flights were accomplished with four "B" model RPVs. One RPV loss (RPV 015) was incurred because of operational errors within the GCS; however, all-in-all the B Phase test program was a great success. Target detection and recognition flights were conducted with both unstabilized and stabilized sensors. Resolutions of the video and Phase II camera were evaluated. Both Eye-Safe and YAG laser target designation were accomplished successfully at a range of 20 km from the ground control station. Scoring of YAG laser hits on a target board was also accomplished.

Upon conclusion of Phase B, two U.S. Army crews were certified to operate the Aquila system, and there was no doubt about the worth of an RPV system for U.S. Army battlefield use. Two ground control stations, one complete Aquila system, and nine RPVs were turned over to the U.S. Army during July and August 1977 for use on the USAEPG and USAFABD test programs.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Tables		Page

Section I
INTRODUCTION

The Aquila Remotely Piloted Vehicle System Technology Demonstrator (RPV-STD) Program was undertaken by the U.S. Army for evaluation of a potential battlefield surveillance and target designation system. Since the hardware was only required to have a limited life – i.e., long enough to achieve completion of the U.S. Army evaluation tests – there was no requirement for a "militarized" system which could be repeatedly moved and used for many years in an operational theater.

As a prelude to the U.S. Army RPV-STD evaluation test programs, a contractor-managed test, demonstration, and system performance requirements validation flight test program was planned. This flight test program was formulated into two test phases (A and B), which would ultimately demonstrate the degree of compliance with the performance goals established in the contract and would validate the concepts and approaches chosen.

The Phase A series of flight tests provided, initially, the opportunity for the contractor to refine hardware-software designs and to check out operational procedures in the areas of:

- Site setup
- Prelaunch vehicle and ground support equipment checkout
- Ground station initialization
- Launcher operation
- Retrieval system operation
- Radio control flight operation in early stages

- Test crew expertise
- Manual autopilot control
- Automatic waypoint navigation control
- Approach guidance
- Search, loiter, and dead reckoning modes
- RPV aero-performance
- Command and data-link performance
- RF system performance
- RPV autopilot performance
- Special instrumentation
- Semiautomatic retrieval
- U.S. Army student training

Demonstration and validation flights were scheduled after "debugging" of the respective system elements was complete. Therefore, usable performance data were obtained during the later flights of the series.

Once the basic system elements had been demonstrated and validated, Phase B was entered. These flights were reserved for solving any open test items from Phase A, for evaluating and demonstrating sensor system performance, and for qualifying the U.S. Army crew members in operating and maintaining the Aquila system elements. During the sensor system evaluation phase, maximum utilization of a U.S. Army U-1A Otter aircraft was made. This aircraft was used extensively for RPV and sensor operator training, software verification, and radio frequency system and data-link verification on a low risk basis prior to committing expensive flight hardware to an RPV. An Otter-RPV integrated flight test program was thereby accomplished. Each of the five sensor types was evaluated in flight. They were as follows:

- Phase I. A two-axis gimballed unstabilized TV with remote field-of-view (FOV), focus, and iris controls
- Phase II. An added 35-mm minipan panoramic camera

- Phase III. An addition to the Phase I sensor – a rate stabilized line-of-sight, automatic light compensation, and contrast centroid autotracker
- Phases IV and V. An added neodymium YAG laser and self-erecting vertical gyro plus the capability for burst offset display (Several units were fitted with an Eye-Safe laser for initial tests and training.)

1.1 VOLUME III ORGANIZATION

This report describes the flight test program as planned and executed. Detailed flight-test program results are presented in References 1 and 2. This volume highlights those results while describing what was required to field the test program, what tests were performed, what the objectives were, and what problems were encountered.

The volume is divided into three sections covering the following:

- Section 2. Crows Landing tests
- Section 3. Phase A testing at Fort Huachuca
- Section 4. Phase B testing at Fort Huachuca

Each section contains a facility description, a test hardware description, test objectives, test results, and summary/conclusions.

1.2 ACKNOWLEDGMENTS

Facilities and range support offered and available to the field team at Fort Huachuca were very good. Many organizations and persons could be listed and thanked for their cooperation during the Phase A and Phase B flight test program, but the list would be too long. However, some of the individuals whose personal interest and drive contributed so much to the success of the project must be recognized. Mr. John Summers of the AVSCOM RPV Field Office is thanked for his relentless drive for completion of a successful program. He

arranged, with the help of Mr. Harry Murray and Mr. John Vesco, for all facilities, equipment, transportation, camera coverage, military support, etc. Mr. Murray, the Assistant to the Contracting Officer Technical Representative (ACOTR) from the Eustis Directorate, is thanked for his cooperation, advice, and coordination on the flight test program. Mr. Vesco is an extremely co-operative and effective individual and he is to be commended for his efforts in providing materials, facilities, surveys, etc. Mr. Marshall Bryan of the Range Operations branch of the USAEPG is also thanked for his cooperation in scheduling, and seemingly-never-ending rescheduling, flight test "windows" for the Aquila program between higher priority flight test programs.

LMSC is grateful to the U.S. Navy for its support during the flight test phase at the Crows Landing Naval Auxiliary Landing Field, California.

Section II

PHASE A TESTING – CROWS LANDING

The basic objectives of the flight tests at Crows Landing were threefold:

- Verify the airworthiness of the RPV
- Verify performance of autopilot guidance loops
- Verify integration of the RPV and GCS

The flight tests commenced on 1 December and concluded on 17 December 1975, with a total of six successful flights. There were no aircraft losses. To varying degrees, each of the objectives was met, and several required design changes were identified and incorporated prior to the series of automatic launchings and recoveries scheduled for Fort Huachuca.

2.1 FACILITY

The Crows Landing Naval Auxiliary Landing Field near Patterson, California, was used for the first flight tests for several reasons:

- Short supply line to the LMSC Sunnyvale plant
- Available runway with low volume of air traffic
- Adequate airspace and clear terrain

Figure 1 is a plot layout of the Crows Landing Naval Auxiliary Landing Field and shows the orientation of the two runways, the three planned RPV flight courses, the Aquila launch area, and the location of the line shack used for RPV maintenance. Figure 2 is a photograph of the line shack and RPV checkout area. Figure 3 is a photograph of the RPV with the tricycle landing gear on the runway.

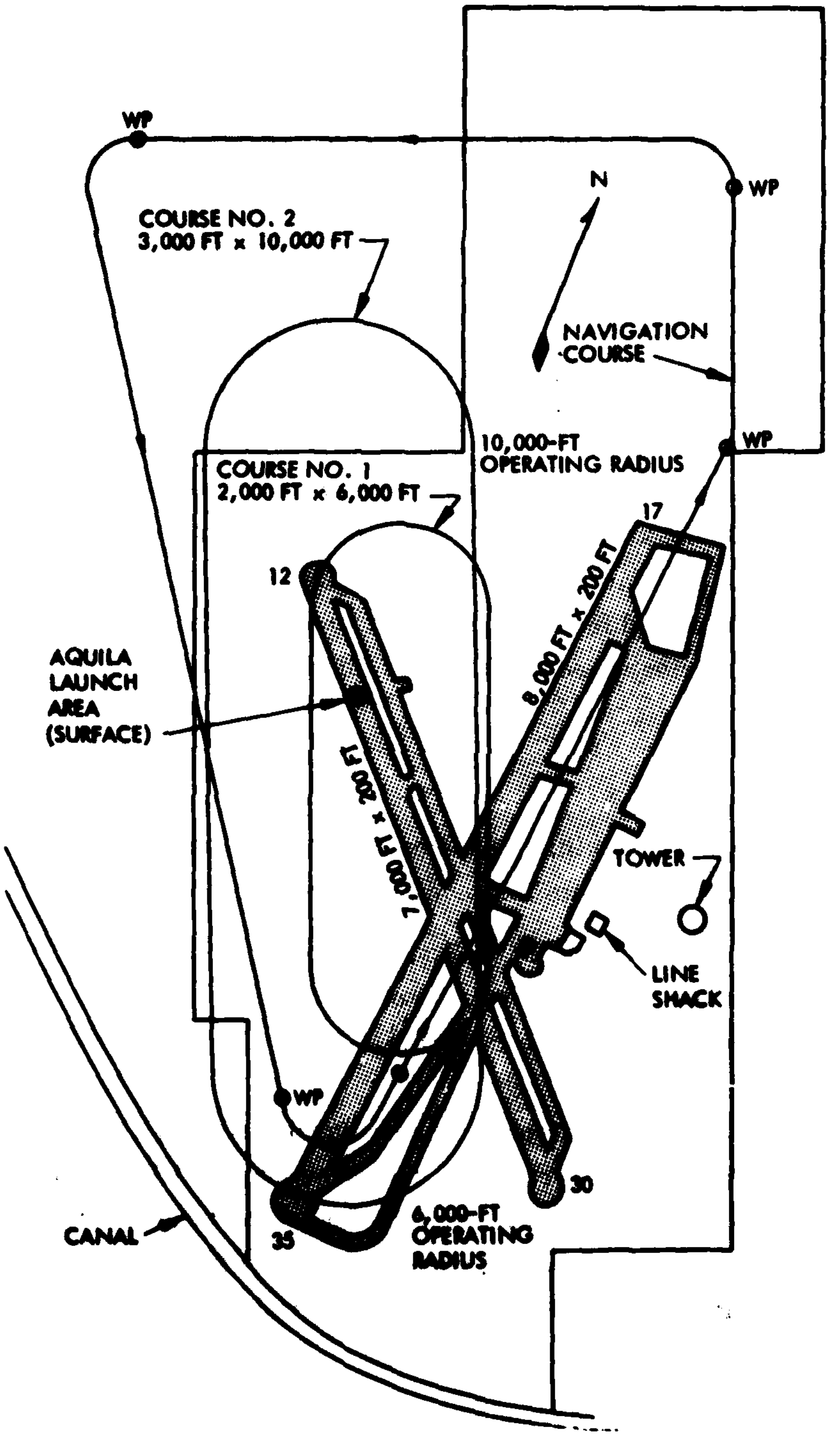

Figure 1. Crows Landing Naval Auxiliary Landing Field

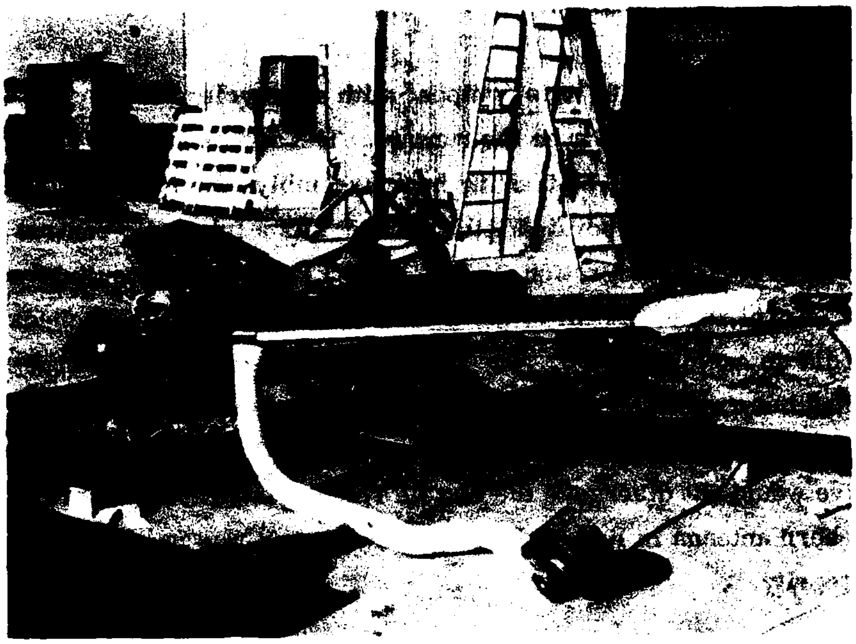

Figure 2. Line Shack and RPV Checkout Area

Figure 3. RPV With Tricycle Landing Gear

2.2 HARDWARE DESCRIPTION

As shown in Figure 3, the RPV was equipped with a tricycle landing gear for radio control takeoff and landing on the runway. The addition of this landing gear necessitated removal of the trailing hook assembly, the payload dome, and the payload protector. Incorporated into the RPV was a full radio control (RC) flight mode for pre-GCS-integration flight tests. LMSC's RC consultant was Mr. Gary W. Korpi, who flew all of the Crows Landing and Fort Huachuca RC flights, and did an exemplary job. The retrieval subsystem was not present at Crows Landing but was initially integrated into the system at Fort Huachuca, Arizona. One attempt to utilize the launcher at Crows Landing failed, when the solenoid valve would not disengage the shuttle release latch. On several flights, a hand-held horn antenna in lieu of the autotrack system was used to maintain data-link integrity.

2.3 TEST APPROACH/PLAN

The test approach taken during Phase A was to accomplish verification of system attributes in a logical sequence. This included RPV autopilot, RPV airworthiness, and GCS software elements. Table 1 shows a scorecard of the planned flight test objectives versus the flight test objectives accomplished.

The test method called for takeoff from the runway under RC control at approximately 93 km/h (50 knots), followed by a climb to the test operating altitude, minimum 150 m (500 ft) AGL, and a transfer to the manual mode. The RPV operator in the GCS would then fly the intended flight plan, with the RC pilot as a backup. As shown in Figure 1, the maximum distance on any of the three flight courses, from the RC pilot to the RPV, was 2,000 m (6,500 ft), well within his visual range. Upon completion of the flight plan, the RPV was to be landed by the RC pilot.

TABLE 1. CROWS LANDING FLIGHT TEST PROGRAM OBJECTIVES SCORECARD

Objectives	Flight					
	1	2	3	4	5	6
RPV Airworthiness (Performance)						
Speed	x	●				
Climb/descent		●	●	●	x	x
Autopilot (Flight Control)						
Heading rate	x	●	●	●	●	●
Airspeed		x	x	●	●	●
Altitude		x	●	●	●	●
Pitch rate (short period) damping	x	●	●	●	●	●
Phugoid damping	x	●	●	●	●	●
Data-Link Performance	●	●	●	●	●	●
Waypoint Guidance			x	x	x	●
Loiter Performance			x			

KEY:

x Objective planned but not evaluated.

● Objective planned and evaluated.

Automatic launch and semiautomatic recovery were not planned because of expected unavailability of that hardware. The launcher, however, became available for a seventh flight at Crows Landing but malfunctioned as previously mentioned.

2.4 SUMMARY OF CROWS LANDING FLIGHT TESTS

This section summarizes each of the Crows Landing Flight Tests, from 1 to 17 December 1975.

2.4.1 Flight 1

Aquila RPV 001 took off at 09:42, 1 December 1975, from Crows Landing runway 35. The total flight time was 1 min 43 sec. The primary objectives of the flight were to evaluate: (1) RPV maneuvering capability and airspeed, (2) autopilot heading rate, pitch rate, and phugoid damping loops, and (3) operational flight test of the data-link system.

The RPV takeoff speed was 93 to 96 km/h (50 to 52 knots) after a takeoff roll of approximately 210 m (700 ft). The vehicle was in the RC mode and performed a climbing left-hand turn to an altitude of 120 m (400 ft). During both takeoff and climbout sequences there were intermittent data-link losses. At 36 sec into the flight the data link was lost. The RPV went into the link-loss mode. As programmed, it started a right turn. However, the turn was level, not according to the programmed climb. At a flight time of 1 min 7 sec (31 sec after link-loss mode) initiation of engine shutoff occurred. At this point the RPV was parallel to runway 17. Control was shifted to the backup omnidirectional antenna, and RC control was established. A dead-stick landing was accomplished on runway 17. The RPV was not damaged in the landing. The data-link performance objective was partially met. All other objectives were not evaluated because of shortness of the flight.

2.4.2 Flight 2

Aquila RPV 001 took off at 16:28, 12 December 1975, from Crows Landing Runway 30. The total flight time was 11 min 50 sec. The primary objectives of the flight were evaluation of the following:

- Aerodynamic stability
- Autopilot heading loop, pitch rate (short period) damping, and phugoid damping loops
- Engine performance
- Data-link operation

The RPV takeoff speed was 93.7 km/h (50 knots) after a takeoff roll of approximately 180 m (600 ft). The RPV climbed to 335 m (1,100 ft) where a right-hand racetrack of 1,830 by 610 m (6,000 by 2,000 ft) was established. The RC pilot flew the first orbit of the racetrack. He found that the RPV was difficult to trim for straight and level flight because of a slightly insufficient negative elevon control. During this orbit the RC pilot executed gentle turns, climb, and dive maneuvers. The autopilot tests were then initiated. The RPV was landed in the RC mode. All of the objectives of the flight were attained.

2.4.3 Flight 3

Aquila RPV 001 took off on 16 December 1975. The flight time was 13 min, 42 sec. The primary objectives of the flight were to evaluate the autopilot airspeed, heading, pitch rate, and phugoid damping loops.

After takeoff and climbout, a brief checkout was made of altitude, heading, and pitch rate loops before engagement of the phugoid damping loop. Approximately one orbit of the test racetrack was completed when the engine began erratic behavior. The test was terminated and the RPV landed in the RC mode. Because of the engine problem, flight objectives were only partially met. The engine problem was found to be fuel-line air leakage at the carburetor.

2.4.4 Flight 4

Aquila 001 took off on Flight 4, 50 min after the termination of Flight 3, on 16 December 1975. The flight time was 15 min 20 sec. The primary objectives of the flight were:

- Evaluation of the engine repair as a result of Flight 3
- Evaluation of the autopilot heading rate, airspeed, altitude, pitch rate and phugoid damping loops

After takeoff and climbout, a racetrack pattern was established. The previously checked loops were verified and the phugoid damping loop was evaluated on the first three orbits. The airspeed loop was evaluated during the remainder of the flight. RPV recovery was made in the RC mode.

2.4.5 Flight 5

Aquila RPV 001 was flown for the third time on 16 December 1975. The total flight time was 27 min. Primary flight objectives were as follows:

- Autopilot altitude loop evaluation
- Full autopilot control response in manual mode

The RPV took off and was flown to the flight test altitude in the RC mode. The autopilot airspeed, heading, and phugoid damping modes were engaged briefly. The autopilot altitude loop was then engaged and operated nominally. The RPV was then flown in the full autopilot and manual modes for approximately 4 min. Recovery was in the RC mode.

2.4.6 Flight 6

Aquila RPV 001 was flown for 20 min 8 sec on 17 December 1975. The primary objectives of the final test flight at Crows Landing were:

- Evaluation of RPV performance in the fully autopilot mode
- Evaluation of waypoint navigation

The RPV was flown to the test altitude in the RC mode. It was then flown for several orbits of the racetrack pattern in the manual autopilot mode. The RPV was then positioned for flight in the waypoint guidance mode. On engagement of waypoint guidance, it immediately entered a double-standard right turn. The RPV was repositioned, via manual autopilot control, for waypoint navigation. Again the RPV entered a double-standard right turn on engagement of waypoint navigation. The flight test was terminated and the RPV landed in the RC mode.

2.5 SUMMARY AND CONCLUSIONS

During the six successful flights at Crows Landing, the following specific objectives were accomplished in the areas indicated:

- RPV airworthiness. Validated basic flightworthiness with limited functional and performance data, including speed, maneuvering capability, and rate-of-climb/descent measurements
- Autopilot guidance. Completed checkout of heading rate, airspeed, altitude, pitch rate damping, and phugoid damping flight control loops in the autopilot
- RPV-GCS integration. Validated basic system compatiblity on the basis of data-link performance (command, telemetry, and video links), RPV flight under auto and manual autopilot control, and partial evaluation of waypoint guidance

Completion of waypoint navigation validation and planned evaluation of loiter flight performance were delayed pending transfer of flight operations to Fort Huachuca.

In conclusion, the general airworthiness of the RPV, the integrity of the RPV-GCS interface and the autopilot functional capability had been evaluated and qualitatively validated. The flight space limitations at Crows Landing made achievement of quantitative data difficult. It was decided to move the flight test activities to the U.S. Army Electronic Proving Ground, Fort Huachuca, Arizona, since Fort Huachuca offered the air space required to obtain quantitative data of RPV performance and waypoint navigation, and to validate launch and recovery techniques.

Section III
PHASE A TESTING – FORT HUACHUCA

Based on the experience gained at Crows Landing in regard to operational procedures and the maturity of the hardware and software, it was decided that a deviation from the original flight test plan was necessary. Accordingly, flight test planning was changed to a flight-by-flight basis rather than adherence to the rigid plan previously outlined. The objectives for a flight in this mode were flexible and were based upon the accomplishments of previous flights. The generally planned test sequence called for evaluation of RPV airworthiness, RPV autopilot control loops, radio control flight, launcher operations, ground control station operations, data-link performance, manual autopilot control, waypoint guidance control, loiter, search, aircraft performance (climb, descent, altitude, etc.), automatic approach, recovery, Army crew training, and dead reckoning. As the software matured and problems were resolved, the flight tests progressed through the list of general objectives.

3.1 FACILITY

The Fort Huachuca Military Reservation is divided into two useful range areas for RPV or drone test flights. The east range, used quite often for artillery practice, contains a spatial resolution target for airborne optical system evaluation and consists of approximately 115 km^2 of range at an average altitude of 4,300 ft. The terrain is flat or gently sloping downward toward the east, and is sparsely covered with brush and 4- to 8-ft trees. There are adequate dirt roads for access to all areas of the range, and ample survey points of known coordinates and altitude. Walkie-talkies must be used for communications on the east range. This range can be seen from a great portion of the west range. The FPS-16 tracking radar, located on the west range, has a direct line of sight to all of the east range. Entry to the east range by RPVs is restricted to a 1-km wide corridor that is located 2-km north of Libby Army Airfield.

The west range consists of approximately 37 km^2 of land with airspace useful for RPV testing. The terrain is generally rolling hills with an average altitude of 4,800 ft. Fort Huachuca possesses airspace rights beyond the west range boundary, where there are mostly private lands. The southern edge of the west range is bounded by the Huachuca Mountains, which peak at an elevation of approximately 6,000 ft. The terrain is predominantly clear of brush and trees. There are adequate dirt roads for access to all areas of the range, and ample survey points of known coordinates and altitude. Communications on the west range were arranged through Range Operations, and consisted of commercial walkie-talkies.

Generally, the weather and flying conditions at Fort Huachuca are very good. Visibility is usually at least 50 mi. The rainy season occurs during July and August; however, showers can occur later in the year. Generally all rain storms are also electrical storms. Because of the open terrain, hills, and high spring and summer temperatures of 60°F to 100°F, there are many days with significant winds. The strongest wind season is during the first half of the year, but winds can be present any day of the year, to some extent. Usually, the winds on the west range are under 20 km/h and are from the west. Gusts of 5 to 10 km/h are not unusual. On many occasions, wind direction has shifted 180 deg during a 2-hr flight period. Temperatures during the winter months can drop to 30°F.

Access to Fort Huachuca by civilians is controlled and can be arranged through the post security organization.

Figures 4(a), (b), and (c) are topographic maps of Fort Huachuca, which show the relative layout of the east and west ranges with respect to the cities of Huachuca City and Sierra Vista. The site areas used during Phase A flight testing are marked on Figure 4 as I, the RPAODS area; and II, the Sycamore Canyon area. For the first 9 months of flight testing, the RPAODS area near

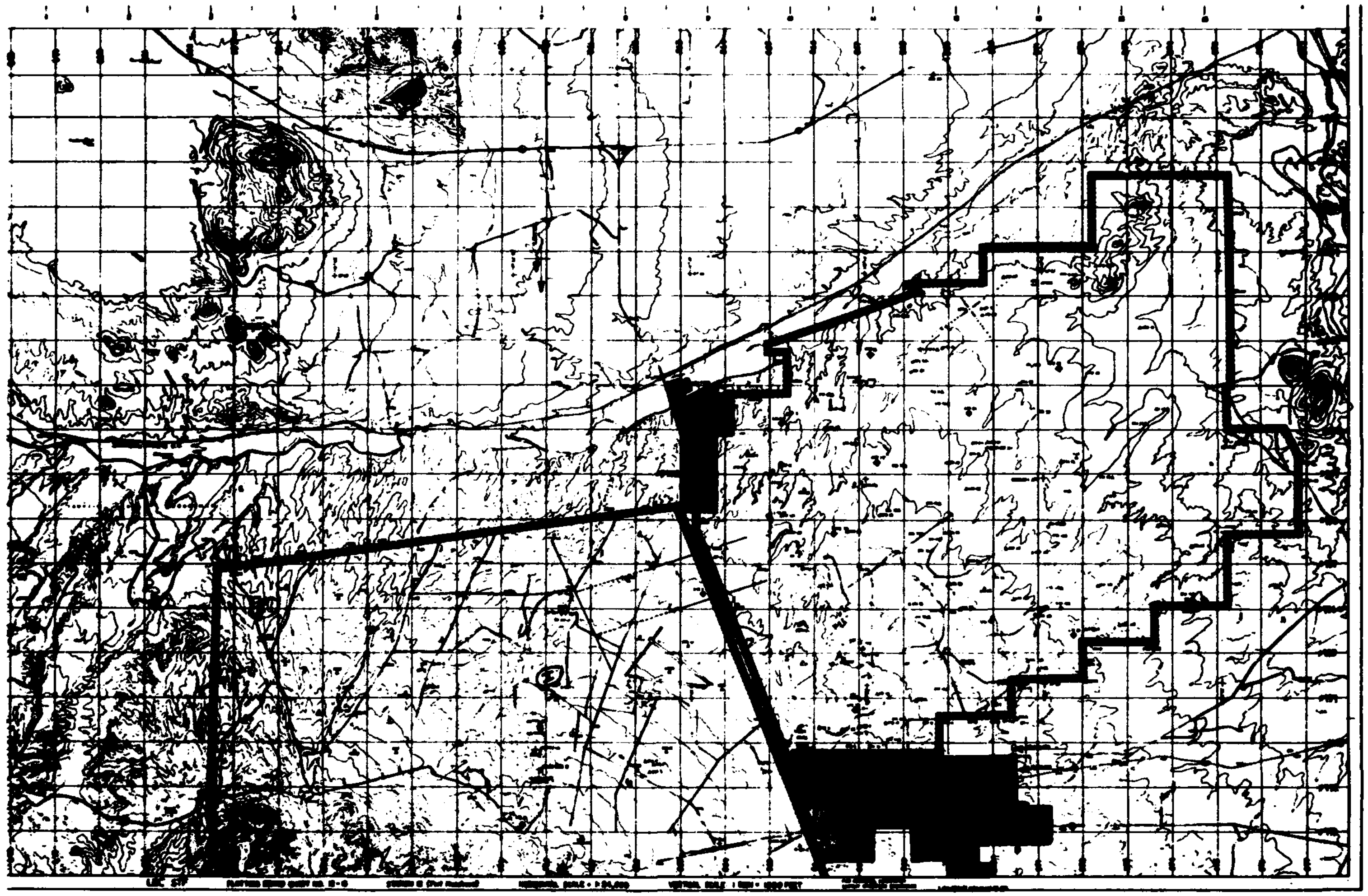

Figure 4. Topographic Maps of Fort Huachuca (a) Overall Map

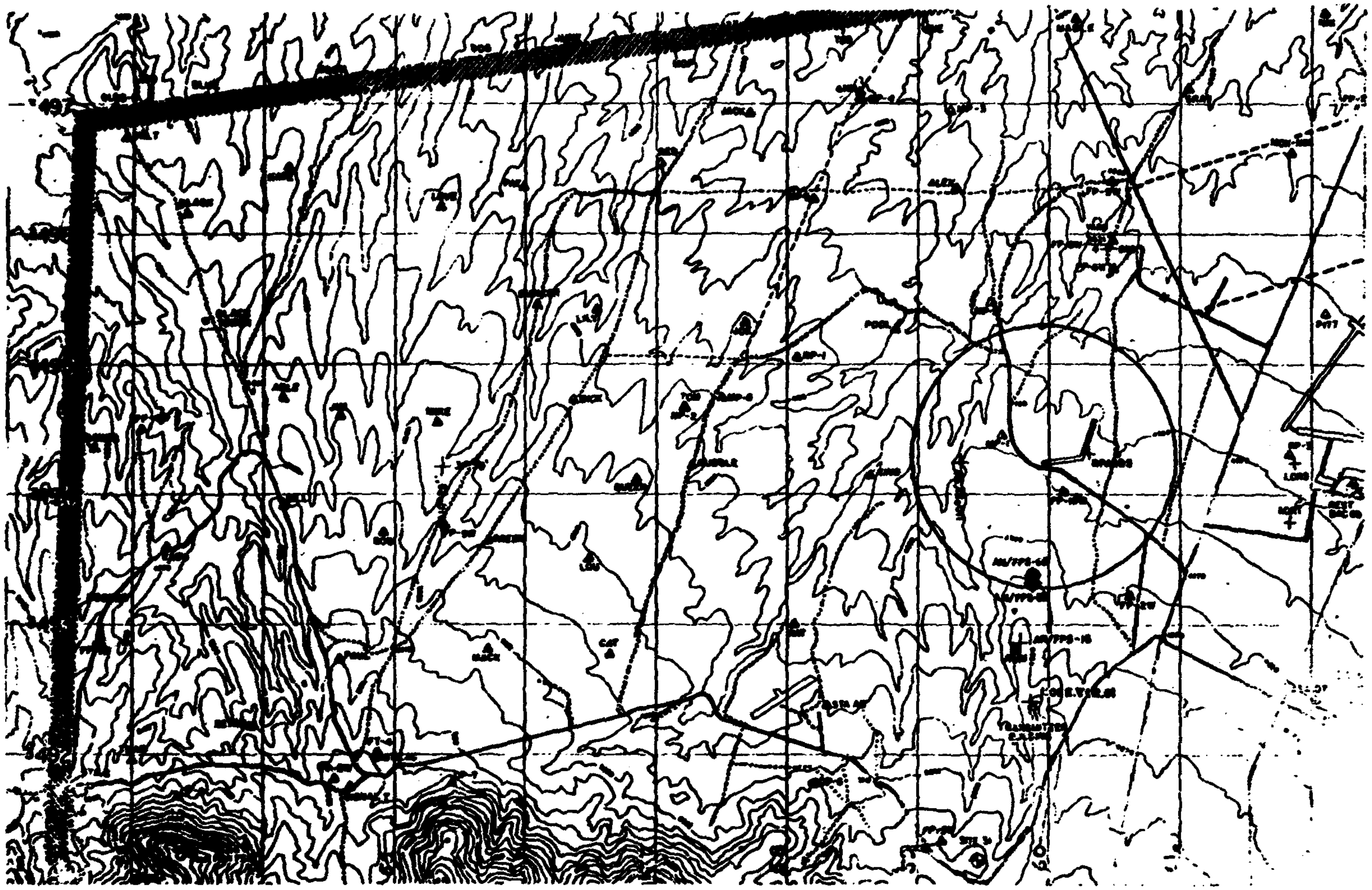

Figure 4. (Cont.) (b) Fort Huachuca West Range

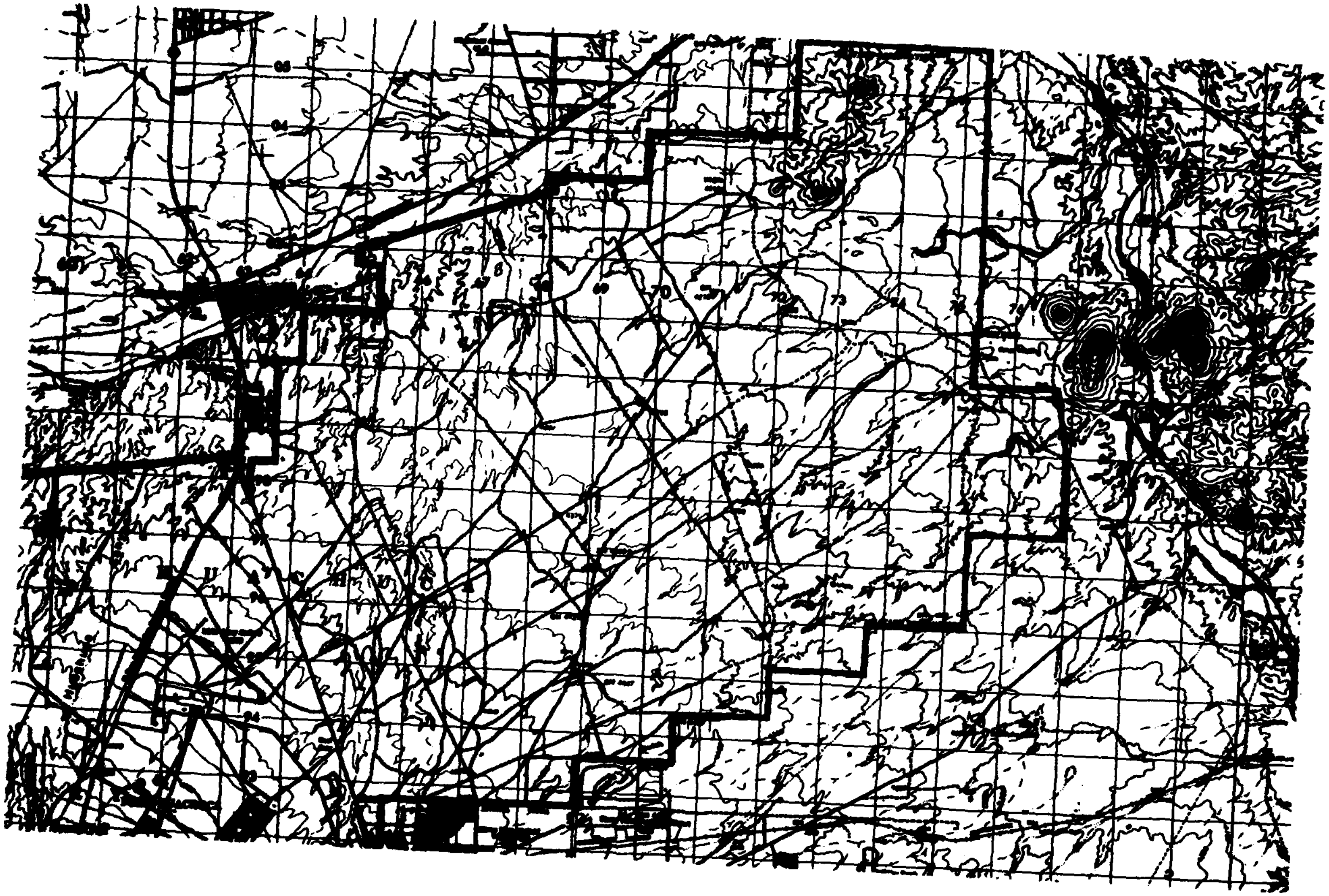

Figure 4. (Cont.) (c) Fort Huachuca East Range

Libby Army Airfield was utilized. During the early Phase A flights, where maximum range from the ground control station was not an objective, the RPAODS area afforded the option of either easterly or westerly flights. Toward the east, a distance of approximately 15 km, and toward the west, approximately 8 km, was available to the reservation boundaries.

The RPV test site at the RPAODS area was flat, and was located at the west edge of a 1,000-ft long asphalt covered east-west runway. The recovery net was oriented along an east-west line. A shorter military-type, metal-section runway extends in a north-south direction and is adjacent to the asphalt runway at the east end in an L-shaped fashion. Figure 5 is a photograph of the RPAODS area showing the work building in the foreground and the RPV site at the far end of the runway. Figure 6 is a photograph showing the early 1976 site area with the hook-type recovery system and a backup retrieval system, which ultimately was not required.

During October 1976, the RPV test site was moved to the Sycamore Canyon area, where a greater onpost distance could be achieved for RPV flights. This site was located near the north-west boundary of the post near the Drone Test Facility. The terrain at Sycamore Canyon is rolling hills with an increasing average elevation at the south and southwest sections of the west range. The RPV site was located at survey point BLACK, approximately one-half mile north of the Drone Test Facility.

The maintenance building (No. 11660) was made available to LMSC and was far superior to the building made available at the RPAODS area. The maintenance building is located within a large compound with two smaller buildings, one of which was available for storage. The compound is large enough for all of the GFE trucks, trailers, generators, etc. West of the compound is a concrete helicopter pad and beyond that is a canyon. Laser boresighting to the rise 1 km to the west was accommodated several times from the helicopter pad. The maintenance building contains approximately 9,700 ft^2 of floor space with bay

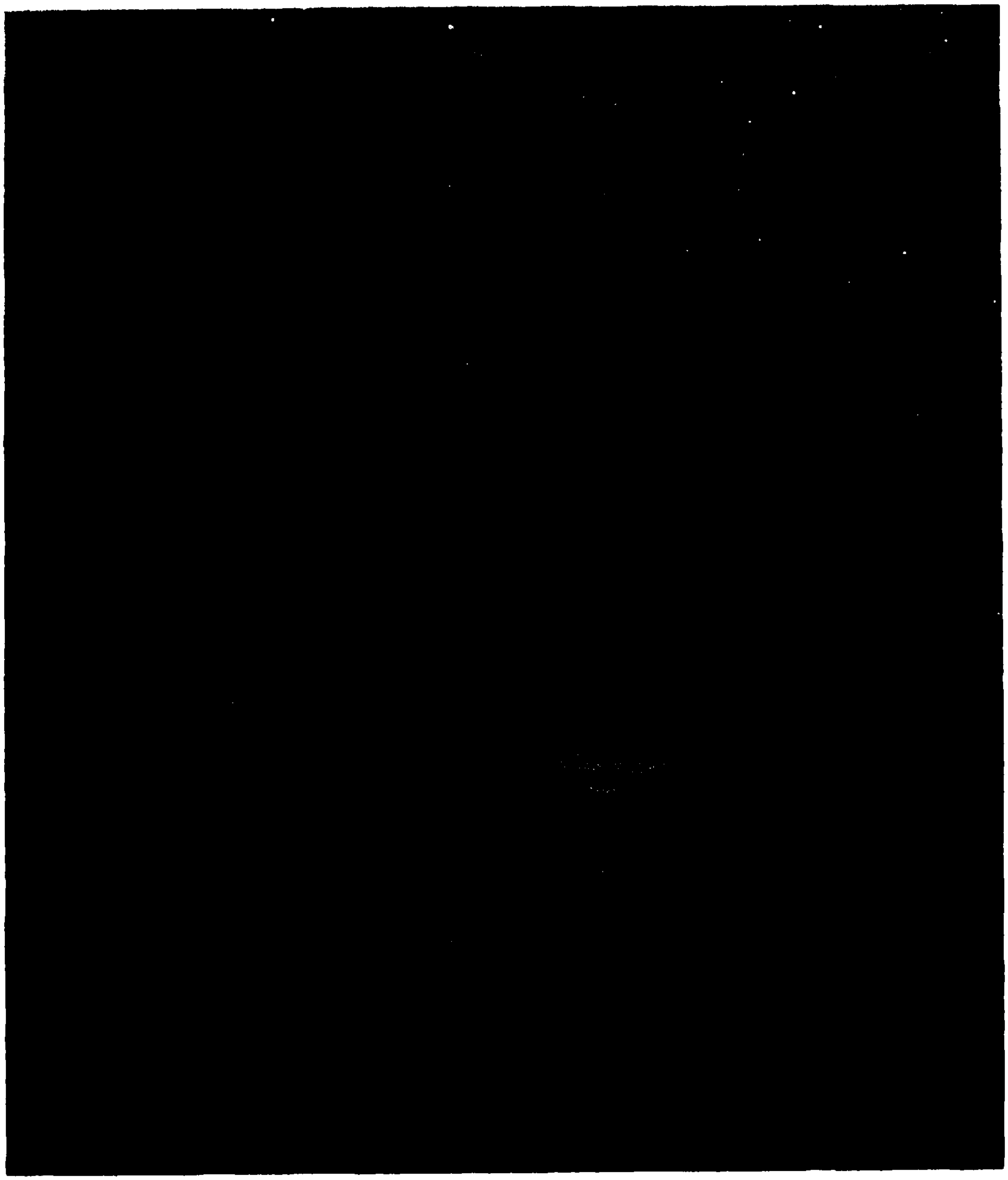

Figure 5. RPAODS Area

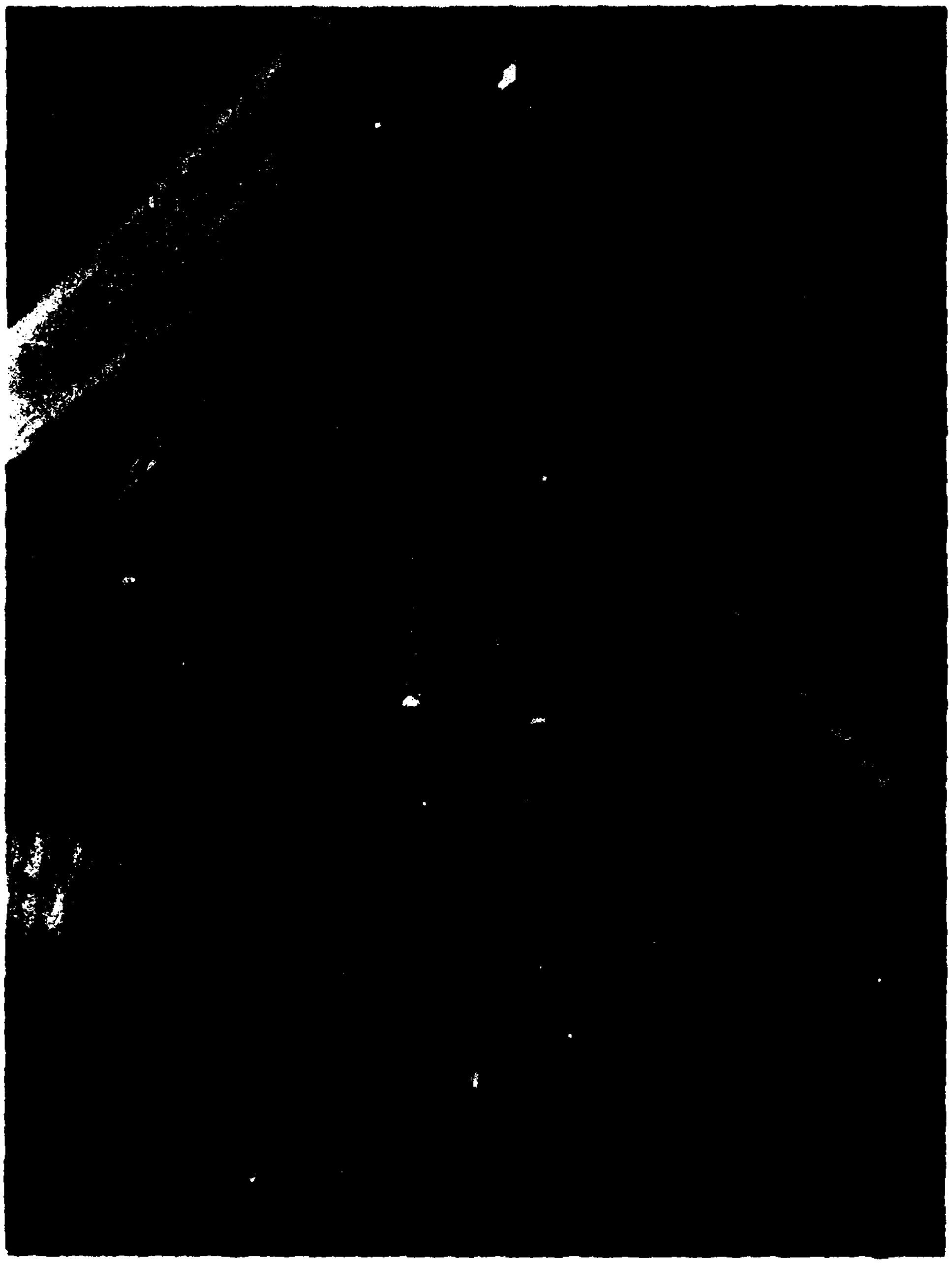

Figure 6. RPAODS Test Site

doors high enough to accommodate a launcher vehicle or GCS (without autotrack antenna attached). Spaces were available for offices, electronics shop, parts storage, or even classroom activities. The central high bay area consists of approximately two-thirds of the total floor space. This area was used for RPV assembly and checkout, GCS modifications, and launcher maintenance. A common restroom facility is available. The building also contains hot water, an air compressor, ample lighting, and 115 V, 60 Hz power.

3.2 HARDWARE DESCRIPTION

After the flight test series at Crows Landing, RPV-001 was returned to the LMSC Sunnyvale plant for removal of the landing gear and addition of the hook assembly, solenoid, payload protector, skeg pin, and ballast. Not all of these modifications were completed when the aircraft was delivered to Fort Huachuca early in January 1976. A piggyback TM system was part of the early RPV flight equipment because additional RPV status data channels were required for evaluation of autopilot performance. Checkout of the RPV was laborious for the first few weeks because of the suitcase tester's inability to check all desired interfaces and its incomplete readout of PROM programs. Autopilot loops were checked by injection of known voltages into the flight control package via harness breakout boxes and by monitoring RPV responses and breakout signal levels. Special checkout procedures were prepared for this activity. In some cases the GCS was used to augment RPV checkout. During March and April, procedures were prepared for utilization of the suitcase tester for RPV checkout, and programming of PROMs was completed. A Sony TV was installed in RPVs 001, 005, and 007 for the initial flights at Fort Huachuca. Phase I unstabilized sensors were installed in RPVs 002, 003, and 004. C-band beacons for range radar tracking were supplied by Range Operations and were installed in the RPVs throughout the flight test program.

GCS-002 was installed on a 2-1/2 ton, GFE army truck, and was parked at the west end of the RPAODS east-west runway. The autotrack antenna and weather

station were installed at Fort Huachuca; however, initially there was only a high gain antenna with its narrow pencil beam restrictions. A hand-held horn antenna with remotely activated coaxial switch was included on the top of the GCS for flights at elevation angles greater than 10 deg. A special test board was installed in the GCS Electronics Interface Unit to allow selection by the RPV operator of certain autopilot loops and flight modes.

The radio control (RC) pilot carried a modified Kraft radio control box that was hardwired to the GCS. The box provided override capability so that control of the RPV could be taken over at the flip of a switch. The GCS uplink was used for RC and GCS generated commands to the RPV.

Launcher 02 was shipped to Fort Huachuca from Crows Landing. Initially, the shuttle velocity measuring equipment was incomplete but was later revised. The launcher was otherwise complete to the design maturity of that date. At that time the design did not require a permanently mounted blower, lanyard, or dryer. Shuttle shots had been accomplished at the LMSC Sunnyvale plant. At Fort Huachuca, the launcher was retested by firing (dry), shuttle shots and then blivet shots. (The blivet was a flat metal plate, with skeg, of the same weight as a light RPV.) The blivet was launched with various pressures. Distance to impact was measured and compared with theoretical pressure and weight tables.

The retrieval system was shipped to Fort Huachuca from All American Engineering Co. and was erected at the RPAODS test site. Flights 7 through 14 (Flight 7 was the first flight at Fort Huachuca) utilized the original horizontal arrester-line array at the horizontal parallel-strap net. The RPVs contained a deployable tail hook to engage the arrester lines during retrieval. Starting with Flight 15 the vertical barrier retrieval system without arrester lines and RPVs without hooks were evaluated. Figures 7, 8, and 9 are photographs of the arrester-line horizontal retrieval systems with energy absorber. Figure 10 is a sketch of the RPV with the hook assembly deployed prior to engagement. (Refer to Volume II, Section 5.4, Retrieval System Evolution.)

Figure 7. Arrester Lines

Figure 8. Horizontal Net

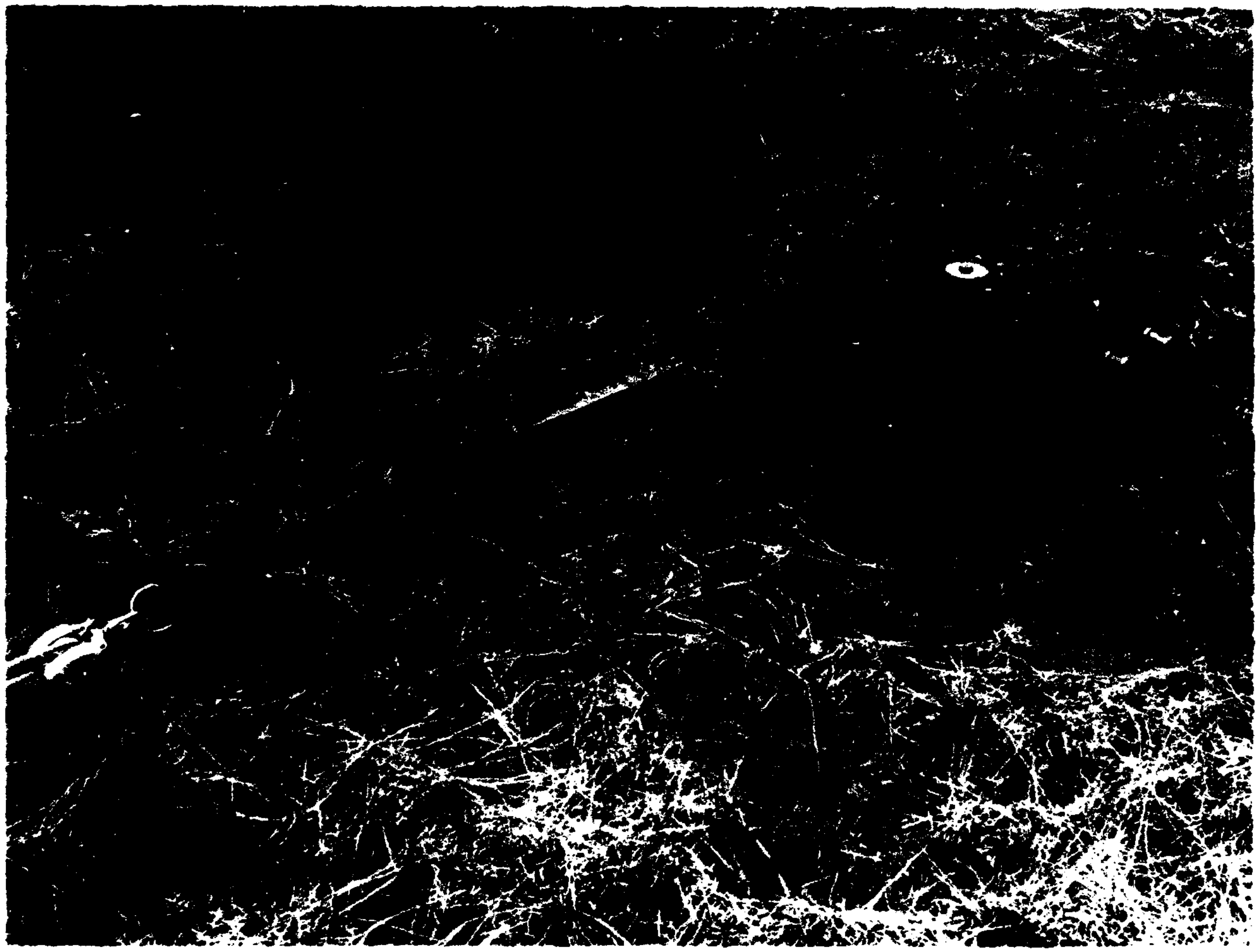

Figure 9. Retrieval System Brake

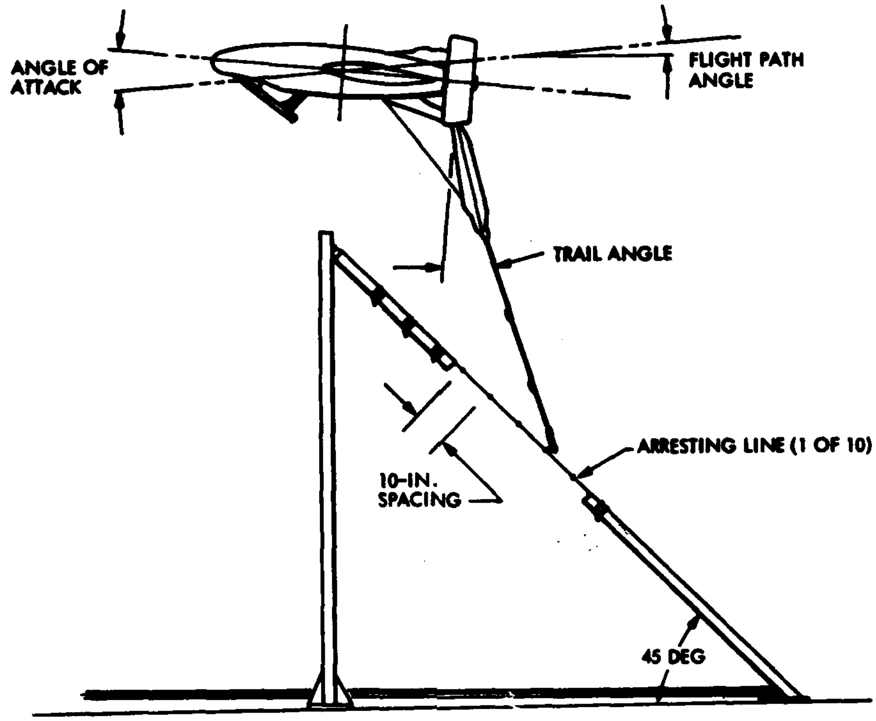

Figure 10. RPV Hook Assembly

GFE 30 kW and 45 kW trailer-mounted generators, with fuel pod, supplied 3-phase, 115 Vac power to the GCS and launcher. Two generators always were required to be online for RPV flights. One generator was dedicated to the GCS air conditioner and the other to the GCS equipment and launcher. All loads could be switched onto and carried by one generator in case of a generator failure during flight.

LMSC provided an instrumentation van with a data magnetic tape recorder and a selectible 8-channel chart recorder. This equipment facilitated rapid flight analyses and real-time in-flight support.

3.3 TEST APPROACH/PLAN

In preparation for the flight test program at Fort Huachuca, an operational test plan evolved. This flight test program was structured into two series:

- Design validation tests. These were to be performed by the contractor to verify that system performance met design specifications. These tests were to provide early identification of potential problems and to establish requirements for rework and/or retest prior to the system validation tests.
- System validation tests. These were to be performed by the contractor to demonstrate to the U.S. Army that performance of the Aquila system was in compliance with military requirements.

Both the design validation tests and the system validation tests were to be structured into five test phases. The test objectives were the same for both test series except that the purpose in the first case was for U.S. Army operator experience and contractual requirement demonstration. These phases and objectives were as follows:

- Phase I
  - Aircraft flight characteristics and performance
  - Autopilot performance
  - Data link and command control
  - Sensor real-time TV surveillance capability
  - Launch system performance
  - Retrieval system performance
  - Operational techniques and procedures
  - Training techniques
  - Assembly and checkout procedures
  - Maintenance and repair procedures

- Phase II
  - Photographic camera capabilities and performance in reconnaissance missions
  - Operational techniques related to photographic reconnaissance missions
- Phase III
  - Aerial system target detection and identification
  - Autotrack performance
  - Operational techniques related to target detection, identification, and tracking
- Phase IV
  - Laser range finder performance
  - Target acquisition performance
  - Navigation accuracy
  - Target location accuracy
  - Artillery fire adjustment evaluation and operational techniques
- Phase V – Laser designation performance and operational techniques

The design validation test series was planned for a 6-month duration with the system validation test series starting 2 months after the start of the design validation test series. The 2-month lead was to provide time for corrective action and procedures preparation. This plan was in effect when flight test operations began in January 1976 at Fort Huachuca. Adherence to that plan and schedule deteriorated over the following 4 months because of aircraft losses that resulted from a variety of hardware and operational deficiencies. Flight operations were terminated by direction of the Army after a total of seven flights at Fort Huachuca when the sixth RPV was lost on 28 April 1976. On 4 May 1976, the contractor was directed to enter into an indepth system reliability improvement program, which involved hardware, software, and operational procedures. Volume II, Section 2.5, System Reliability Improvement Program, outlines this 4-month effort, which also included the addition of a

parachute backup recovery system to the RPVs. Reference 1 describes the parachute system.

During suspension of flight test activity at Fort Huachuca, a thorough review was also made of the scope, intent, and objectives of the remaining RPV-GCS development system validation flight test efforts. Concern was expressed for a flight test plan that would provide the following:

- Rationale for the requirements of each flight and the "building block" logic that relates each flight to subsequent flights
- Elimination of reliance on a 100-percent program success approach by providing repetitive and/or redundant flight objectives, where feasible, without penalty to other objectives; further, to provide for contingency flights to cover changes in the scope of requirements and to cover flights in which circumstances prevented accomplishment of requirements

The Aquila System Validation Flight Test Plan, EM No. 5583-50, dated 30 July 1976, Appendix A, was prepared, and it accomplished all these objectives. A 14-flight program, including 4 planned contingency flights, was planned, and is shown in Figure 13 of that test plan. That document also indicated three phases to the new validation program:

- Phase A
  - Software completion and mission performance in the areas of way-point guidance, mission navigation, RPV initialization, approach guidance, search, loiter, dead reckoning, etc.
  - Launcher validation
  - Retrieval validation
  - RPV performance
  - Data link validation

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(1) Lockheed Missiles & Space Company, Inc., Aquila RPV System Test Report, CDRL AOOD, Parachute System Development Tests, LMSC-L028081, Part 3, Sunnyvale, Calif., 1 Mar 1977

– Ground control station validation

– Procedures validation and LMSC test team qualification

- Phase B – Sensor mission validation
- Phase C – U.S. Army training and flight demonstration

As can be observed, there were no longer separate series of contractor design validation tests and government system validation tests. They were combined into one flight test program. Ultimately, the Phase C U.S. Army training and flight demonstration tests were consolidated into the Phase A and Phase B flight tests. On 25 August 1976, the contractor unsuccessfully attempted to resume flight testing (Flight 14A). A premature release of the RPV by the launcher during the launch cycle resulted in the loss of RPV-008 without the aircraft ever having been airborne under its own power. During the following three weeks, modifications were made to the launcher (refer to Volume II, Section 5.3.4, Launcher Evolution, for technical details of the problem and fixes). The contractor again resumed flight testing on 13 September 1976 (Flight 14) with the RPV hook assembly and arrester-line horizontal net configuration. That retrieval attempt was unsuccessful and resulted in adoption of the vertical ribbon barrier system for all subsequent flights. The Phase A flight test program concluded on 23 February 1977 with Flight 37. Only one RPV was lost, and that loss was attributed to a procedural error and broken wire at the RC pilot's control box. U.S. Army operators from Fort Sill participated in on-the-job training in all facets of flight operations starting in December 1976. Eight additional flights were flown through 23 February 1977 for additional crew training and resolution of a few open items in the Phase A test series.

During the course of flight test operations at Fort Huachuca, several special test support functions were provided.

Early in the test program, an RC pilot controlled the RPV in flight, until transfer to the RPV operator inside the GCS could be accomplished. However, the

RC pilot retained override capability and was able to take back control of the RPV in case of system problems. The only functions provided in the RC mode were rpm control and elevon control (up, down, right, and left). For retrieval, the RC pilot was positioned approximately 100 ft behind the retrieval net. A sighting stand was used for glide slope orientation. Generally, the RC pilot was able to maintain the RPV on a 2- to 4-deg descent angle. As a result of the system reliability improvement program, an augmented RC mode was provided, which gave the RC pilot the advantage of several autopilot control loops. These loops assisted the pilot in controlling the RPV during climbs, turns, straight and level flight, and descents. Gradually, after more and more of the system's automatic features were validated, the RC pilot's role diminished. During the flights of December 1976, he played merely a backup role. The RC function was totally eliminated starting in January 1977.

After Flight 14 a vertical ribbon barrier with horizontal net was set up at Fort Huachuca. Prior to committing an RPV to that system, the Sky Eye drone (a DSI product) was flown under the RC control of G. Korpi, and was retrieved successfully four times in the vertical ribbon barrier net at various airspeeds. The DSI drone weighed 135 lb and was representative of an Aquila RPV. The RC pilot flew several orbits of the area and then positioned the aircraft for retrieval. All flights and retrievals were successful. These successes not only validated the vertical ribbon barrier concept but also provided a training opportunity for the RC pilot preparatory to Aquila retrievals.

Launcher tests were accomplished routinely to verify readiness of that subsystem. During Phase A, several modifications were made to the launcher (refer to Volume II, Section 5.3.4, Launcher Evolution, for a detailed description). During the early portion (early 1976) of the flight test program at Fort Huachuca when RPV launchings were widely separated, shuttle and blivet shots were made to ensure readiness of that equipment. Whenever modifications were made to the launcher or launcher/RPV interface or whenever major maintenance was accomplished, the same combination of shuttle and blivet

shots was made. Shuttle shots were a qualitative test to indicate that the subsystem elements were functional. Blivet shots were accomplished to provide quantitative verification that the launcher was operating within design limits for pressure versus shuttle velocity under load. This test also was used as an aid in revealing degradation of the subsystem.

3.4 RESULTS

As discussed in the previous section, Phase I flight tests at Fort Huachuca began on 22 January 1976 with Flight 7 and were interrupted on 28 April 1976 after Flight 13 for the reliability improvement program and again after the attempted Flight 14A of 25 August 1976. The Phase A flight test program was resumed on 13 September 1976 with Flight 14. This phase of the flight test program was completed successfully on 23 February 1977 with Flight 37. The bulk of the Phase A flight test objectives had been completed by 21 December 1976 with Flight 29. Items left unvalidated at that time were the squared "S" search pattern and the dead reckoning mode. These items required additional software changes as well as hardware modifications associated with dead reckoning. Open problem areas included roll/yaw oscillations (refer to Volume II, Section 3.4.4.2, Guidance Mode Evolution, for a detailed discussion of this problem) at a range greater than 10 km, and main lobe autotrack when switching from the high gain to low gain antenna. Several modifications to the system elements were determined to be mandatory prior to initiation of the Phase B flight test program. Because of lead times involved, these B changes could not be implemented until March 1977; however, evaluation of their critical aspects before then was essential. Therefore, several additional flights were scheduled for January and February 1977. Flights 30 through 37 were accomplished to provide this information, and to complete open items in the Phase A flight test program.

3.4.1 Flights 7 Through 13

The first seven flights at Fort Huachuca were the most frustrating of the program, because the problems which surfaced seemed random in nature at the time. Six aircraft were lost during the seven flights, with one successful arresting line/hook retrieval. Even though many RPVs were lost, a great many features of the system were debugged, refined, and demonstrated. By the end of April 1976, the following development test objectives had been demonstrated to varying degrees:

- Engine operation
- RPV electrical/flight control system
- Launcher operation
- Data link
- Ground station operation
- RPV stability
- RPV aerodynamic performance
- Radio control operation
- Manual autopilot control
- Automatic autopilot control
- Waypoint Guidance
- Hook/payload protector deployment
- Operating and checkout procedures

Table 2 is a summary of the first seven flights at Fort Huachuca. Flight objectives, performance accomplishments, and anomalies encountered are identified. A flight-by-flight discussion of the results obtained and changes evolved from those flights are contained in the following sections.

TABLE 2. SUMMARY OF FLIGHTS 7 THROUGH 13

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
7	1-22-76	001	19		Sony	• Launcher performance check • Retrieval system performance check under RC control • RPV aerodynamic performance check without landing gear • Waypoint guidance navigation check	• Launcher performance OK, launch velocity 96 km/h (51 knots) • RC control OK • RPV stability OK • GCS/manual autopilot control OK • Maximum rpm 7100 • Rate of climb OK	• Upon hook deployment, engine shut down by premature microswitch action and RPV dove to impact ground. (Microswitch subsequently removed from all RPVs.)	• RPV totally destroyed
8	2-23-76	002	67		Phase I	• Launcher performance check • Retrieval system performance check under RC control • RPV aerodynamic performance • Autopilot dynamics • Phase I sensor performance • Waypoint guidance navigation • RC flight dynamics • Final approach guidance	• Accomplished launch from GCS • RC control OK • RPV stability OK • GCS/manual autopilot control OK • GCS/waypoint guidance control OK • Sensor video and controls OK • Launcher performance OK • Retrieval system performance OK • RCS control in final approach mode OK	• Payload protector deployed at launch but did not latch • Rate gyro not spun-up prior to launch • GCS plotters indicated wrong RPV position • Antenna azimuth angle error of 180 deg • Payload dome fractured during flight at 75 knots	• Hook twisted
9	3-4-76	002	56		Phase I	• Launcher performance check • RPV aerodynamic performance under manual control • Waypoint guidance navigation • Final approach guidance • Retrieval system performance under RC control • Autopilot performance	• Launcher performance OK • Climbs, descents and turns by manual autopilot OK • Waypoint guidance OK • Autopilot performance OK	• Upon hook deployment RPV descended (rpm at 7000, A/S at 47 to 60 knots until) ground impact	• RPV moderately damaged
10	3-24-76	003	32		Phase I	• Low pitch prop evaluation • Increased elevon throw evaluation • Launcher performance • RPV aerodynamic performance • Final approach guidance • Retrieval system performance	• Launcher performance OK • Climb rate and horsepower improvement with low pitch prop • Hook and payload protector deployment OK	• Under autopilot control, RPV tended to turn right; necessitated return to RC control • Hook engagement incomplete; RPV careened off net to ground	• RPV heavily damaged
11	4-6-76	004	48		Phase I	• Launcher performance • RPV aerodynamic performance • Final approach guidance • Retrieval system performance	• Launcher performance OK • Waypoint guidance performance OK • Waypoint short performance OK • Ground camera acquisition of RPV at range of 3,000 ft • Good rate of climb	• Payload protector deployed at launch • Intermittent status lock • Hook deployment attempts ineffective	• Moderate damage to RPV during attempted runway landing under RC control
12	4-12-76	005	30		Sony	• Launcher performance • RPV aerodynamic performance • Final approach guidance • Retrieval system performance	• Launcher performance OK • Waypoint guidance performance OK • Initial RC control and aerodynamic performance OK	• Engine high temperature indication • RC control became uncontrolled and RPV impacted ground (RPV pilot disorientation occurred at visual limit)	• RPV totally destroyed
13	4-20-76	007	21		Sony	• Launcher performance • Final approach guidance • Retrieval system performance	• Launcher performance OK • RC control OK • Manual and automatic control OK • Hook deployment OK • Aerodynamic performance with hook down OK • Link loss mode OK	• Command link loss due to overheated GCS component. RPV entered 2-min link loss mode until engine shut down	• RPV totally destroyed

3.4.2 Flight 7

On 22 January 1976, Aquila RPV 001 was launched at the RPAODS site for a flight of 19 min, 15 sec. The primary objectives of the flight were:

- Evaluation of launcher and retrieval *system* performance
- Evaluation of RPV performance without landing gear
- Waypoint guidance navigation

The RPV was launched from the pneumatic launcher in the RC flight control mode. The launch velocity was 95 km/h (51 knots) at an engine rpm of 7100. The RPV was taken to an altitude of 300 m AGL, where aircraft responses to RC commands were performed. Upon completion of these tests, the RPV was transferred to GCS control in the manual autopilot mode for further autopilot loop tests. Two minutes later the RPV was returned to the RC mode for retrieval because of an impending weather change. Four practice approaches were made to the retrieval net with good controllability and adequate power for climbout before the arresting hook and payload protector were deployed. Upon *deployment*, the RPV lost power and pitched down into a dive. The RPV was totally destroyed upon ground impact.

The loss of power upon deployment was traced to an improperly installed microswitch, which was activated prematurely by the deployment of the arresting hook. Then, as designed, an electrical sequence was initiated which resulted in engine shutdown. Arresting line engagement with the hook was supposed to activate the microswitch. After Flight 7, appropriate design changes were incorporated to remove the microswitch and thus preclude repetition of this failure mode.

3.4.3 Flight 8

Aquila RPV 002 was launched on 23 February 1976; the flight time was 1 hour, 7 min, 11 sec. The primary objectives of Flight 8 were:

- Launcher and retrieval system evaluation
- Autopilot dynamics
- RPV aerodynamic performance
- Waypoint guidance navigation
- Phase I sensor performance

The RPV was launched remotely from the GCS in the RC mode. During launch, the payload protector deployed; however, Phase I sensor video indicated the protector was not in the fully extended position. The RPV was transferred to GCS control in the manual autopilot mode at 425 m AGL, approximately 2 km from the GCS. Then the RPV was transferred to the waypoint guidance mode. Under this mode, the RPV visually appeared to react as programmed; however, the GCS X-Y plotter indicated that the RPV was in a position 180 deg from its actual position. Additionally, it was determined that the rate gyro was inoperative from the RPV response. During this phase of the test, the RPV made a speed run of 118 km/h (75 knots). Under the resulting aerodynamic forces and other stresses, the payload dome fractured, and portions of the dome passed through the propeller duct, resulting in no RPV damage. Two practice RC approaches were made before making a successful RC retrieval. Final approach mode GCS control checks also were successfully accomplished. Post-flight inspection revealed that the arresting hook was twisted and required replacement.

3.4.4 Flight 9

Aquila RPV 002 was launched in the RC mode on 4 March 1976. The flight time was 58 min, 30 sec, of which 3 min were in the RC mode and the remainder in either manual autopilot or waypoint guidance. The primary objectives of Flight 9 were:

- Evaluation of the launch and recovery systems
- Autopilot performance
- Waypoint guidance evaluation
- RPV aerodynamic performance

The launch was normal with a climbout to 2,000 m MSL (5,500 ft) where a racetrack pattern was established and the RPV transferred to the manual autopilot mode. Then the RPV was flown around the racetrack at two and four times standard rate turns. After that, it was flown to 2,360 m MSL (6,500 ft) and returned to the 2,000 m MSL altitude to evaluate rates of climb and descent. The RPV was flown through two waypoints to evaluate waypoint navigation. Then it was flown in a larger racetrack pattern to further evaluate rates of climb and descent.

The RPV was positioned for arresting hook deployment at 145 m AGL (400 ft). Upon hook deployment, the RPV established a rate of descent of approximately 250 m/sec (700 fpm). The RC pilot could not control the descent, and the RPV was transferred to the manual autopilot mode and commanded to 4,350 m MSL (1,200 ft) at 47 to 60 knots. However, while the descent rate steadily decreased, the RPV continued to descend at full throttle until ground impact.

To correct the excessive drag, inadequate nose-up trim, and climb rate experienced in this flight, a decision was made on future flights to: (1) remove the drag brake, which constitutes the major aerodynamic drag element of the RPV during retrieval, (2) increase elevon throw, and (3) lower propeller pitch.

3.4.5 Flight 10

Aquila RPV 003 was launched in the RC mode on 24 March 1976. The flight time was 32 min, 20 sec. The primary objectives of Flight 10 were:

- Evaluation of launch and retrieval systems
- RPV aerodynamic performance
- Waypoint guidance
- Tracking antenna bearing and range performance
- Final approach guidance

The launch and climbout were normal to 1,600 m MSL (4,400 ft). The autopilot was engaged and was unable to maintain level flight. The RPV tended to turn to the right. It was returned to the RC mode and the autopilot was engaged several more times with the same result. The RPV was returned to the RC mode for retrieval. Two attempts were made before hook engagement. The hook engagement was not complete, and the RPV landed in the horizontal net; it then careened into the air and impacted the ground beyond the net.

Destruction of the RPV prevented determination of the cause of the autopilot anomaly; however, a procedural change was made to verify that rate gyro offset and heading rate trim limits were acceptable prior to launch. A design change was incorporated in the arresting hook to allow a larger line capture area and in the retrieval pendant lines to improve rigging.

3.4.6 Flight 11

Aquila RPV 004 was launched in the RC Mode, on 6 April 1976. The flight time was 48 min, 7 sec. The primary objectives of Flight 11 were:

- Launch and retrieval systems evaluation
- Aerodynamic performance
- Waypoint guidance evaluation
- Final approach guidance

At launch the payload protector deployed minus the drag brake. RPV performance, however, was not degraded during the flight. After initial manual autopilot checks, the RPV was entered into a waypoint guidance test. After the first waypoint, the RPV experienced intermittent status locks and the waypoint guidance test was aborted. The waypoint abort mode of operation was nominal, and the RPV returned to the retrieval area via waypoint abort (WP 80/90) navigation. It was then returned to the RC mode for retrieval. During the retrieval sequence, the arresting hook would not deploy upon command. Several attempts were made,

but the hook remained in the stowed position. An unsuccessful attempt was made to land the RPV on the RPAODS runway, and the RPV was destroyed. Appendix B discusses the anomalies and corrective actions taken as a result of this flight. Electrical circuit design changes were incorporated in the RPV flight control package after this flight to allow resetting of the hook drop logic and to allow repeated hook deployment commands. Payload protector solenoid installation was modified to prevent premature drop due to launch acceleration and shock. The intermittent status locks were found to relate to RPV receiving antenna pattern null areas.

3.4.7 Flight 12

Aquila RPV 005 was launched in the RC mode on 19 April 1976. The flight time was 30 min, 22 sec. The primary objectives of Flight 12 were:

- Launch and retrieval systems evaluation
- Aerodynamic performance
- Waypoint guidance
- Final approach guidance

The launch and climbout were nominal. Following an 11-min period of aerodynamic performance evaluations in the RC mode, the RPV was transferred to waypoint navigation. The RPV flew a flight path of 10 waypoints, as programmed, then it was returned to the RC mode for retrieval. While the RPV was being positioned for arresting hook deployment, RC control was lost. The RPV went into uncontrolled flight and was destroyed on impact.

An analysis of the flight data indicated that the RPV command link operated properly but that an operational problem existed. The approximately 1-mile range at which the RPV was transferred to RC control was beyond the point where the RC pilot could determine RPV attitude. The pilot failed to recognize that the RPV had become inverted; therefore, all the commands from that time

on were 180 deg out of phase. RC model airplane fliers generally make either a transparent section in one of the air vehicle wings or apply a distinctive orientation paint pattern so that they can be sure which wing is in what position during a turn. RPV 005 did not have such an indicator at that time although wing tip paint had been included on prior RPV flights. The RC pilot was unsuccessful in gaining proper control of the RPV, resulting in its crash.

After this flight, the RPVs were provided with distinctive orientation paint markings, and very strict RC flight command and control procedures were implemented.

3.4.8 Flight 13

Aquila RPV 007 was launched in the RC mode, on 28 April 1976. The flight time was 20 min, 55 sec. The primary objectives of Flight 13 were:

- Launch and retrieval system evaluation
- Final approach guidance navigation

The launch and climbout were nominal. The RPV was flown in a racetrack pattern, under RC control, prior to successful autopilot engagement and checkout. Then, the RPV was positioned for RC retrieval and the arresting hook deployed. After hook deployment, the RPV was returned to autopilot control and performed aerodynamic tests in the retrieval configuration. During these tests, the command link was lost and the RPV entered the link-loss mode, functioning as designed. After a 2-min spiral climb, the engine shut down without the link being reestablished. Then the RPV descended to impact.

Cause of link loss was attributed to GCS component overheating. Later this was confirmed by a simulated GCS test on 29 April 1976. Design changes to the cooling air distribution system within the GCS were identified to correct this flight critical problem and were later implemented. Refer to Volume II, Section 5.2.4.2, Provisions for Console Equipment Cooling.

3.4.9 Flights 14 Through 29

The restructured Phase A flight test and validation program objectives are shown in Table 3, Flights 14 through 29 Objectives and Accomplishments. Also shown are the actual flight test accomplishments during the 16 flights that actually occurred during the 14-week period, 13 September to 21 December 1976.

A review of Table 3 reveals that the major area of concern encountered during these tests was the validation of the semiautomatic retrieval system. The first successful semiautomatic retrieval occurred on Flight 21 rather than Flight 18 as scheduled. This delay was the result of a change from the arrester line retrieval system to a vertical barrier retrieval system developed independently by Lockheed. This change was implemented because of continual developmental problems with the arrester line system and the loss of an RPV on 13 September 1976. The success of the other flight test objective segments followed the proposed schedule rather closely; the only exception was the validation of search and loiter patterns, which were delayed significantly due to problems in refining the associated software.

The parachute backup recovery system was installed in the RPVs during this series of flights. A Sony TV camera was substituted for the sensor subsystem on all RPVs with a parachute.

Table 4 is a summary of Flights 14 through 29 and includes the objectives, performance, and anomalies associated with each flight.

3.4.10 Launcher Incident (Flight 14A)

On 25 August 1976, an attempt was made to launch RPV 008 on the first flight of the restructured Phase A test program. Immediately after launch first motion, the forward portion of the RPV separated from the shuttle. The RPV began a pitchup motion which continued throughout the launcher stroke. This resulted

TABLE 3. FLIGHTS 14 THROUGH 29 OBJECTIVES AND ACCOMPLISHMENTS

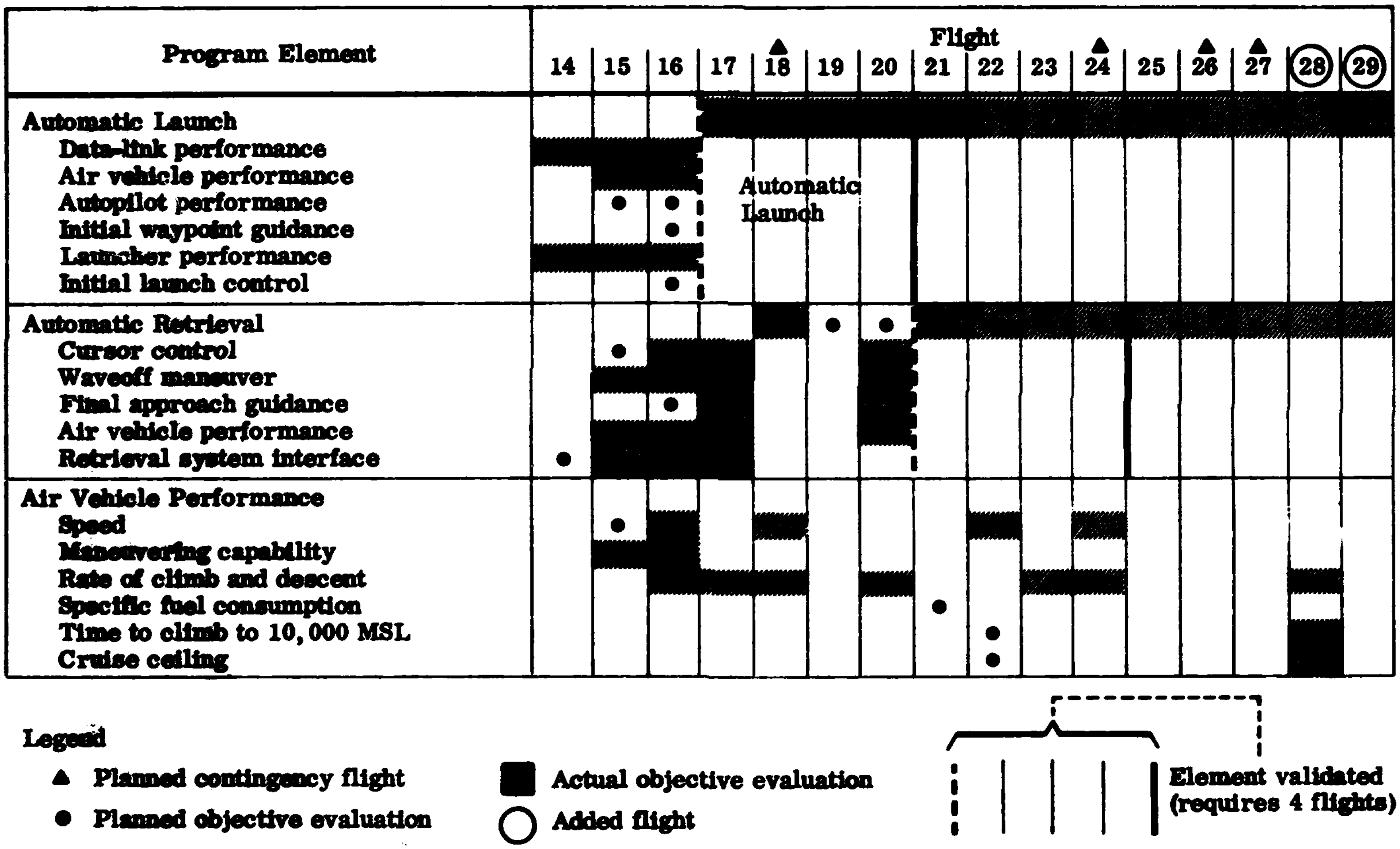

TABLE 3. (Cont.)

Program Element	Flight 14	15	16	17	▲ 18	19	20	21	22	23	▲ 24	25	▲ 26	▲ 27	28	29
Data Link																
Command control status, close range																
Command control status, inter. range									●							
Command control status, long range												●				
Video status, long range												●				
Link protection and loss																
Mission Element Performance																
Waypoint guidance		●	●									●				
Loiter pattern							●					●				
Search pattern, expanding spiral							●									
Search pattern, squared S												●				
Search pattern, moving box									●							
Dead reckoning navigation										●						
Software																
Prelaunch and launch			●													
Initial waypoint			●													
Waypoint navigation																
Loiter pattern							●									
Search patterns							●									
Dead reckoning										●						
Retrieval			●													
Ground Control Station																
Data General diagnostics																
Prelaunch checkout																
RPV navigation						●	●	●	●							
RPV position plotting			●			●	●	●	●							
Approach path			●	●												

Legend ▲ Planned contingency flight ■ Actual objective evaluation

● Planned objective evaluation ○ Added flight

TABLE 4. FLIGHTS 14 THROUGH 29 SUMMARY – FINAL PHASE

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
14	9-12-76	009	15		Sony	• RPV/launcher interface check • RPV flight-worthiness check flight (after reliability improvements) • RPV/GCS interface changes check flight • Hook recovery in RC mode	• Launcher performance OK • RPV/launcher interface OK • RPV aerodynamic performance in RC mode OK • RPV/GCS interface OK	• Data link dropouts at high elevation angles and steep roll angles • RC approach too low, RPV flew through arrester lines into horizontal support	• RPV moderately damaged
15	10-4-76	011	21		Sony	• Evaluate augmented RC mode • RC recovery with vertical barrier retrieval system	• Augmented RC mode performance OK • Retrieval with vertical barrier in straight RC mode OK	• Several short-term status link data dropouts occurred when switching between high and low gain antennae	• Wing tip and nose cap damaged slightly
16	10-8-76	011	36		Sony	• System checks preparatory to launch in automatic mode • RPV aerodynamic performance • Retrieval in vertical barrier	• Prelaunch procedures validated for automatic launch • Performance data obtained including rate of descent and level flight characteristics • Retrieval with vertical barrier in augmented RC mode OK	• Ten status link data dropouts occurred • Parachute deployed in net when payload protector was grounded	• None
17	10-16-76	011	42		Sony	• Launch in automatic mode • Waypoint navigation • Final approach guidance checks • Retrieval with vertical barrier net in augmented RC mode	• Launch in automatic waypoint mode OK • Waypoints flown as programmed • Final approach guidance maneuvers with sensor control performed. RPV response indicated system gains too high • Rate of descent inadequate without drag brake	• Accelerometer malfunctioned and caused phugoid oscillations above 6000 rpm	• RPV receiving antenna broken during retrieval • Payload protector rivet sheared
18	10-22-76	011	46		Sony	• Launch in automatic mode • Waypoint navigation • Aerodynamic performance • Final approach guidance checks • Augmented RC retrieval • Drag brake evaluation	• Launch in automatic waypoint mode OK • Waypoints (38) flown as programmed • Aerodynamic performance at 4 air-speeds obtained • Descent rate with drag brake OK for semi-automatic retrieval • Waypoint navigation accuracy agreement w/AN/FPS-16 tracking radar	• Climb rate was 15% below expected. Lower pitch propeller to be investigated.	• None

TABLE 4. (Cont.)

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
19	10-28-76	011	9		Sony	• Demonstrate launch in automatic mode • Semiautomatic retrieval in final approach mode	• Automatic mode launch OK • Parachute system operated properly	• RPM control lost in RC mode. Broken wire found in RC box • GCS operator failed to transfer control out of augmented RC mode; therefore no GCS control over RPV	• RPV lightly damaged in parachute recovery RPV repaired and reflown
20	11-2-76	006	53		Sony	• Demonstrate launch in automatic mode • Evaluate final approach pitch-rate gain change • Augmented RC mode retrieval	• Automatic mode launch OK • Final approach mode checks OK • Augmented RC mode retrieval	• Software error caused final approach waypoint altitude error (70 m high) • Northing track error of 40 m • Data link dropouts (rec. sensitivity 14 db below spec and cracked coaxs found)	• No damage to RPV except for loose skeg pin • RC cable worn (bare wire showing) • Two cracked coax connectors found
21	11-14-76	006	31		Sony	• Demonstrate launch in automatic mode • Semiautomatic retrieval in final approach mode • Check flight after move to Sycamore Canyon	• Automatic mode launch OK • First successful semiautomatic retrieval with three practice approaches and aborts) • All system elements functioned properly after move to Sycamore Canyon	• Auto track antenna locked onto minor lobe near ground station • Lower carburetor linkage snap ring came off and linkage separated • Impacted vertical net dead ctr	• None
22	11-20-76	006	27	16	Sony	• Demonstrate automatic launch • Demonstrate waypoint navigation • Evaluate loiter and spiral search patterns • Demonstrate semiautomatic retrieval	• Automatic mode launch OK • Waypoint navigation OK • Semiautomatic retrieval OK	• RPV wandered in yaw during loiter and search mode checks. Subsequent software rate gains and heading smoothing changes incorporated • RPV altitude too low on first two practice final approaches req. altitude increases to approach pattern waypoints	• None
23	11-22-76	006	43	16	Sony	• Evaluate loiter performance • Evaluate system performance to a range of 14 km • Demonstrate semiautomatic retrieval	• Automatic launch OK • Waypoint navigation OK • Semiautomatic retrieval OK	• Same yaw problem during loiter as Flt. 22 (software not yet changed) • Roll/yaw oscillations beyond 10 km when flying away from or towards GCS	• Blade antenna snapped during retrieval
24	12-3-76	006	46	17	Sony	• Evaluate squared "s" search pattern • Obtain rate of climb and descent data at various airspeeds • Demonstrate semiautomatic retrieval	• Two squared "s" search patterns accomplished • Semiautomatic retrieval validated • Rate climb and descent obtained at 83 and 90 km/h and 1700 m MSL	• Squared "s" pattern not square (software later modified) • Upper carburetor butterfly shaft broken	• None

TABLE 4. (Cont.)

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
25	12-7-76	012	13	18	Sony	• Evaluate effects of revised software on squared "s" search pattern	• Automatic launch accomplished • Retrieval in augmented RC mode accomplished	• Data link dropouts after launch caused mission to be aborted (loose internal connector on RPV receiver found) • Left side of payload protector not locked (pin stuck)	• Blade antenna snapped during retrieval • Left wing tip damage during retrieval)
26	12-10-76	012	67	18	Sony	• Evaluate effects of revised software on squared "s" search pattern and loiter pattern • Semiautomatic retrieval • Full operation by Army flight crew	• Loiter pattern acceptable • Squared "s" search pattern improved but not sufficiently • Army crew performance good • Army sensor operator performed retrieval	• Severe pitch-up motions during flight (accelerometer later found to have excessive friction)	• None
27	12-14-76	012	41	18	Sony	• Demonstrate squared "s" and expanding spiral search patterns • Demonstrate loiter pattern • Full operation by Army flight crew	• Squared "s" search pattern not symmetrical • Expanding spiral search pattern OK • Loiter pattern OK • First mission totally operated by an Army crew	• Slight yaw perturbation when RPV passes through north heading in search and loiter	• None
28	12-15-76	006	33	19	Sony	• Demonstrate system performance to a 20 km range • Demonstrate climb performance to 9000 ft MSL • Demonstrate waypoint navigation • Full operation by Army flight crew	• Achieve maximum range of 20.2 km with good data link • Achieved maximum altitude of 9800 ft MSL • Army crew performance good • Climb data obtained	• Roll/yaw oscillations beyond 11.5 km range (same as Flt 23) • Horizontal net cross strap caught behind knuckle joint and caused it to collapse	• Blade antenna broken during retrieval • Payload protector rivet sheared • Zenon flash lamp broken
29	12-21-76	012	40	19	Sony	• Demonstrate loiter pattern • Demonstrate squared "s" search pattern • Evaluate pilot's ability to use RPV video for retrieval	• Accomplished loiter pattern OK • Accomplished squared "s" search pattern OK • Pilot practice for backup retrieval mode accomplished	• Slight yaw perturbation in loiter when RPV turns through north • Some overshoot in squared "s" turns	• None

in the RPV leaving the launcher at nearly a 90-deg angle of attack, making two complete revolutions before impacting the ground at T + 2.597 sec . The impact point was approximately 30 m in the front of the launcher.

A detailed analysis of this problem identified these contributory factors:

- Improper seating of the RPV relative to the launcher thrust brackets allowed rearward motion of the RPV relative to the shuttle.
- Design of skeg keeper and release mechanism allowed overturning moments sufficient to release the skeg pin.

These factors were felt to be the causes of the launch incident. Appropriate redesign efforts were implemented (refer to Volume II, Section 5.3.4, Launcher Evolution) to correct both areas of design weakness. No further launcher incidents occurred.

3.4.11 Flight 14

Aquila RPV 009 was successfully launched from the RPAODS site on 13 September 1976. The primary objectives of the flight were to:

- Evaluate the redesign RPV/launcher interface
- Evaluate the flight-worthiness of the RPV after incorporation of reliability improvement changes
- Evaluate the new RPV/GCS interface as a result of latest changes
- Perform an RC mode recovery with the hook/arrester line retrieval system

All objectives were accomplished except the RC mode recovery. Total flight time was 15 min, 24 sec. The RPV/launcher performed as expected. The flight characteristics appeared consistent with the characteristics expected although they were observed only in a qualitative sense because of the tight pattern flown. Airframe weight was increased approximately 14.5 lb by the installation of the parachute recovery system. The closeness of the flight path

also resulted in several video and downlink losses caused either by the RPV being above the GCS antenna or in steep roll angles which prevented RPV antenna line of sight to the GCS.

Three attempts (in the RC mode) were made to retrieve the RPV with the hook/arrester line system. On the third attempt, the RPV was too low and flew through the arrester lines and into the horizontal metal support of the horizontal ribbon landing net. Following this flight, the decision was made to replace the arrester line retrieval system with the vertical barrier retrieval system.

3.4.12 Flight 15 (First Successful Vertical Barrier System Retrieval)

Aquila RPV 011 was launched successfully on 4 October 1976. The primary objectives of the flight were to:

- Evaluate the augmented RC mode
- Achieve successful recovery using the vertical barrier retrieval system

During the flight, controlled roll and pitch maneuvers were performed to evaluate flight control and RPV handling characteristics of the new augmented RC mode. With this mode, the RC commands were summed with the pitch and roll/yaw gyro signals in the autopilot rather than fed directly to the control devices. This technique of RPV control proved stable and well-controlled, effectively reducing the steep-bank angles experienced during the unaugmented or straight RC mode flights.

During this flight, there were several status link dropouts (synchronization losses), the longest lasting about 3 sec. Cause of these drops was attributed to difficulties with the auto-tracking system maintaining lock with the RPV when switching between the high gain and low gain antenna. Such switching occurred because of the close-in flight plan adopted by the RC pilot.

A practice approach was conducted in both the augmented and straight RC modes. For final recovery the RC pilot elected to use the more familiar straight RC mode. The RPV contacted the vertical barrier at an indicated air speed of 100 km/h (54 knots), displaced approximately 60 cm (24 in.) from the vertical center of the barrier with no vertical displacement error.

3.4.13 Flight 16

Aquila RPV 011 was launched successfully on 9 October 1976. The primary objectives of the flight were to:

- Complete validation of those elements required for automatic launch
- Obtain RPV aerodynamic performance data
- Retrieve in the vertical barrier

All objectives were achieved successfully. Total flight time was 38 min, 14 sec. All prelaunch procedural requirements were validated, preparatory to an automatic launch on Flight 17. Aerodynamic data in the manual autopilot mode were obtained for rate of climb and descent and for straight and level flight. The performance data obtained are:

• Rate of climb	513 fpm at 95 km/h
• Rate of descent	205 fpm at 90 km/h
• Rate of descent (payload protector down)	254 fpm at 100 km/h

- RPM and elevon angles as predicted for straight and level flight at 1,621 m MSL

The RC pilot made one practice approach, and then successfully recovered the RPV in the augmented RC mode.

3.4.14 Flight 17 (First Successful RPV Automatic Launch)

Aquila RPV 011 was launched successfully in the automatic mode on 16 October 1976. The primary objectives of the flight were:

- Automatic launch
- Waypoint guidance
- Final approach guidance
- Retrieval

All flight test objectives were met. Total flight time was 42 min, 6 sec. The automatic launch had no discernible flaws with waypoint guidance taking over as programmed at launch plus 24 sec. The RPV flew the waypoint flight path with no anomalies. The final approach guidance tests, which were conducted at an altitude of 273 m (895 ft) AGL, consisted of:

- A pull-up maneuver at maximum rpm to simulate a low-approach abort
- A steep descent to simulate a high approach
- A right-turn maneuver to simulate a horizontal correction

During the abort portion of the test, the RPV climbed too steeply and the indicated airspeed dropped to 63 km/h (34 knots). This anomaly was traced to an accelerometer malfunction, which also caused the RPV to enter a phugoid oscillation whenever the engine exceeded 6,600 rpm. These tests also indicated that the approach guidance gains were too high and would have to be adjusted prior to attempting an automatic recovery.

Aerodynamic performance data were obtained for rate of descent with and without the payload protector deployed. These data indicate that, with the removal of the trailing arresting hook, a drag brake must be reinstalled in the payload protector in order to achieve the 4 deg/sec descent rate required for automatic recovery.

One planned augmented RC mode pass was made over the vertical barrier net prior to the final and successful augmented RC mode recovery.

3.4.15 Flight 18

Aquila RPV 011 was successfully launched in the automatic mode on 22 October 1976. The primary objectives of the flight were:

- Automatic launch
- Waypoint navigation
- Aerodynamic performance
- Final approach guidance
- Augmented RC recovery

All flight test objectives were achieved, and a successfully augmented RC recovery was achieved after a flight of 46 min, 4 sec. The automatic launch was nominal. The RPV flew a flight path consisting of 28 waypoints without an anomaly. Aerodynamic performance in straight and level flight was obtained at four different airspeeds. Additionally, climb and descent rates also were obtained with and without the payload protector deployed to determine the effect of the newly-installed drag brake. The new drag brake increased the descent rate to one which is compatible with the retrieval approach. Two automatic approaches were made; in each case, proper and well-controlled flight responses to velocity and turn commands indicated that the approach guidance and cursor controls operated properly. The retrieval was made successfully in the augmented RC mode.

AN/FPS-16 radar coverage also was provided to measure waypoint navigation accuracy. An analysis of the data indicated a 1-σ correlation of 5 m between the GCS and the AN/FPS-16 on ground track and 5 m in altitude, at elevation angles of less than 10 deg. Maximum RPV range attained was 5 km.

3.4.16 Flight 19

Aquila RPV 011 was launched automatically on 28 October 1976. The primary objective of the flight was to perform a semiautomatic recovery.

The RPV performed satisfactorily until the final approach initiation. At this point, the backup RC pilot thought that the vehicle was descending too rapidly and took over control in the RC mode. He was unable to increase engine rpm by command. Then the RC pilot requested the GCS RPV operator to take over in the manual autopilot mode. The RPV operator also was unable to increase rpm. At this time the RPV was at idle rpm and at an altitude of 47 m (155 ft) above ground level.

The test director then directed deployment of the parachute recovery system. The parachute system operated normally; however, due to the low altitude, the main parachute was still in the reefed condition at RPV impact. The parachute system inverted the RPV properly, so that impact was with the payload positioned upward. This inversion limited damage to the RPV. Total flight time was 9 min. The RPV was repaired and reflown later as part of the Army training program.

A review of the flight failure revealed a broken wire in the RC box cable from the GCS, and that the GCS pilot had not transferred out of the augmented RC mode before commanding manual autopilot control; therefore, the vehicle was not being controlled in any mode.

3.4.17 Flight 20

Aquila RPV 006 was launched automatically on 2 November 1976. The primary objective of the flight was to evaluate the final approach guidance mode after the incorporation of a change shortening the pitch-rate integration time constant.

The flight test objective was met and the RPV successfully recovered in the augmented RC mode after 53 min and 10 sec of flight.

In the first final approach tests, the RPV entered the approach path too high at waypoint 91, the outer marker; as a result, waypoint attitudes were lowered. On the second approach, attitudes were within limits and cursor control (final approach) was engaged at a range of 1,460 m (4,790 ft), and aborted at 950 m (3,117 ft). On the third approach, final approach was engaged at 1,525 m (5,000 ft) and aborted at 555 m (1,820 ft). These tests were terminated when the "fuel-low" indicator light came on; then the RPV was retrieved in the augmented RC mode. The analysis of these two tests correlated very closely to the data generated in final approach guidance simulation testing at LMSC, Sunnyvale.

This was the fourth consecutive automatic launch without any failure. Therefore, the automatic launch mode was considered validated.

3.4.18 *Flight 21 (First Semiautomatic* Approach Guidance Retrieval)

Aquila 006 was flown on 14 November 1976 from a new test site, Sycamore Canyon. The flight duration was 30 min, 26 sec. The move to Sycamore Canyon, in the northeast corner of the Fort Huachuca range, was made to allow for the maximum-range flights, scheduled later in the program. The primary objective of the flight was to perform a semiautomatic retrieval.

The flight plan called for practice approaches to the retrieval barrier, in the final approach mode, with the practice aborted closer to the vertical barrier each time. Each practice was initiated at a range of approximately 1,200 m (3,940 ft). The first practice was aborted at 900 m (2,950 ft); the second at 600 m (1,920 ft); and the final practice approach at 300 m (960 ft). At this time, the sensor operator felt that he could bring the RPV in with the cursor, and was given the go-ahead for an automatic retrieval. The retrieval was "textbook

perfect" with the nose of the RPV impacting the vertical barrier 5 cm (2 in.) high and 5 cm (2 in.) left from centerpoint, as viewed by the sensor operator.

3.4.19 Flight 22

Aquila RPV 006 was flown successfully on 20 November 1976. The primary objectives of the flight were:

- Waypoint demonstration
- Demonstration of both the loiter and expanding spiral search patterns
- Semiautomatic retrieval

All flight objectives were met and the RPV was successfully recovered semiautomatically after 27 min and 7 sec of flight. The launch in the automatic mode was nominal, and the RPV flew the waypoint flight path with no anomalies. However, during both the loiter and search modes, the RPV was not as stable in yaw as it was in the normal waypoint guidance mode. This tendency of the RPV to wander in yaw was very evident from the onboard video recording of the flight. During both the loiter and expanding spiral patterns, these RPV perturbations appeared to be most violent when the RPV was flying due north. The same flight path was programmed into the guidance flight simulator, with the same result. (The loiter pattern and expanding spiral are variations of the same software equation.) The range gains in the software equation were reduced, and the RPV heading was smoothed by increasing the number of data points required. These changes were to be evaluated in later flights in the test program.

The semiautomatic approach guidance retrieval was made successfully, after three practice approaches. During the first two practice approaches, the RPV was judged to be too low, and the final approach waypoints were raised. The approach path on the third practice was nominal and the RPV successfully recovered without damage.

3.4.20 Flight 23

Aquila RPV 006 was flown successfully on 23 November 1976. The primary objectives of the flight were to:

- Perform a loiter pattern
- Evaluate system performance to a range of 14 km
- Retrieve automatically

All test objectives were achieved and the RPV was successfully recovered after 43 min and 14 sec of flight. The loiter equation modification had not been incorporated in time for this flight, because of the on-going simulation proofing. The flight heading-rate commands during loiter indicate the same yaw disturbances as seen on Flight 22. Roll/yaw limit cycling occurred during flight away from and returning toward the GCS. These roll rate amplitudes of 6 deg/sec developed when the GCS rf link range exceeded 10 km and when the RPV flew nearly directly away from or toward the GCS.

A successful semiautomatic recovery was made after two practice approaches.

Subsequent flights were planned for additional intermediate and long-range system performance in which this problem of roll/yaw limit cycling could be analyzed further.

3.4.21 Flight 24

Aquila RPV 006 was flown successfully on 3 December 1976. The primary objectives of the flight were to:

- Perform a squared "S" search pattern
- Obtain rate of climb and descent RPV performance data at various airspeeds
- Retrieve semiautomatically

All flight objectives were achieved and the RPV was successfully recovered after 42 min and 2 sec. Two separate squared "S" search patterns were flown. The first consisted of 2 cycles, progressing in an easterly direction with a period of 2 km and a width of 2.5 km. The second pattern was one cycle in a westerly direction with a period of 3 km and a width of 2 km. As shown in Figure 11, the "S" in both patterns was not square at the ends, but tended to dish-in. The software program for the squared "S" pattern was modified to correct this condition. Future flights would determine whether any further adjustments of the program would be required. Automatic retrieval was accomplished on the second attempt. Because this was the fourth consecutive retrieval without a failure, this mode of recovery was deemed to be validated.

Postflight inspection of the RPV disclosed that the upper carburetor shaft was broken. The point in the flight that the shaft broke could not be determined from the data; however, the engine was unable to achieve maximum rpm after 41 min of flight. For the remainder of the flight, the maximum achievable rpm was 7,400 contrasted with 7,900 earlier in the flight.

3.4.22 Flight 25

Aquila RPV 012 was launched successfully on 7 December 1976. The primary objective of the flight – to perform a squared "S" search pattern using the updated software – was not achieved. The vehicle lock light went out 2 min into the flight, and the TM downlink became intermittent. Two minutes later, the RPV was switched to the manual autopilot mode and the planned mission aborted. The RPV was brought back to the RC control zone and the retrieval was accomplished in the augmented mode on the first attempt. The duration of the flight was 13 min, 44 sec. A postflight inspection of the RPV disclosed that the TM receiver had a loose rf input connector internal to the receiver.

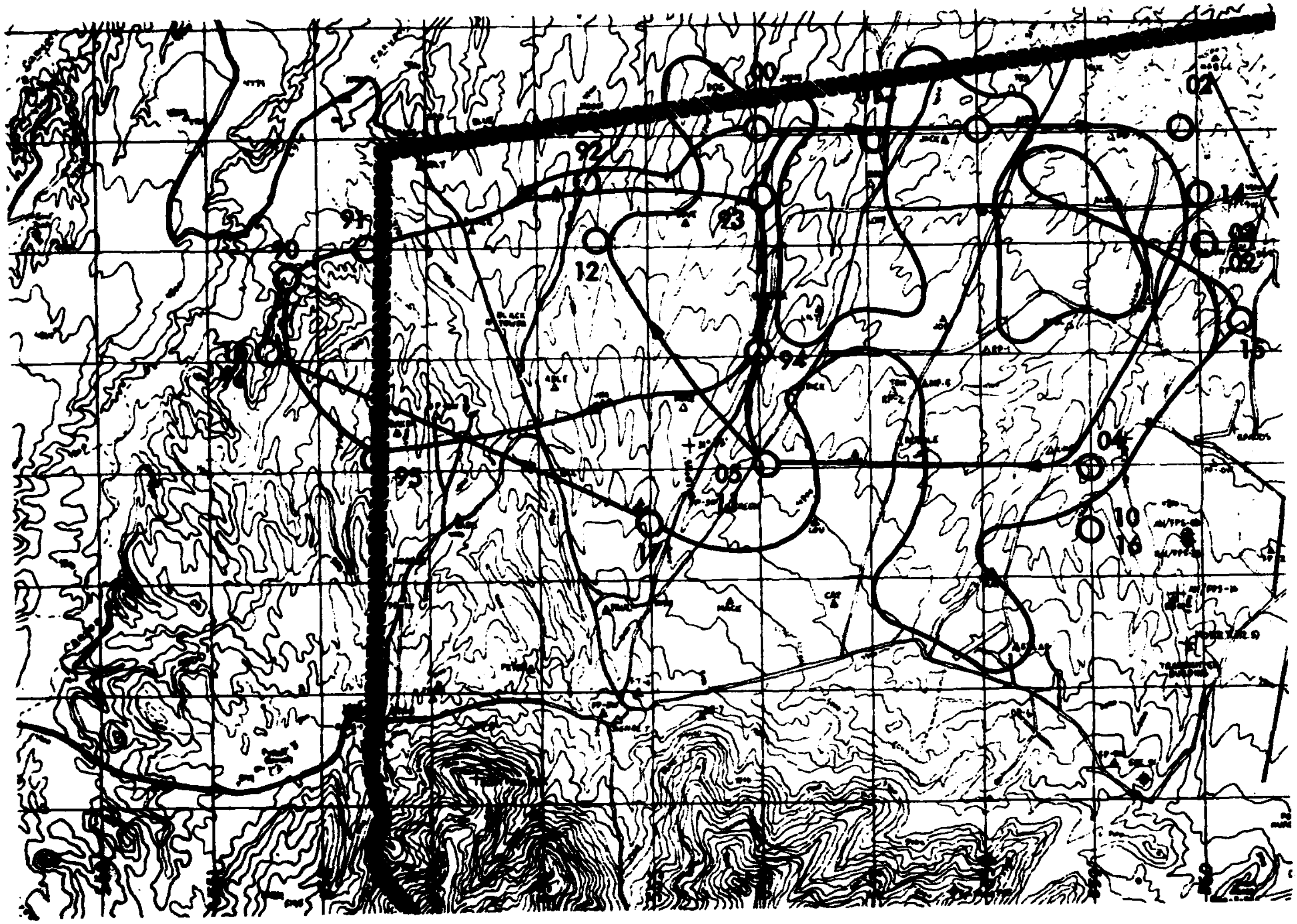

Figure 11. Flight Path, Flight 24

3.4.23 Flight 26

Aquila RPV 012 was flown successfully on 10 December 1976. The primary objectives of the flight were to:

- Perform both a squared "S" search pattern and a loiter pattern
- Automatic retrieval using the 80 series waypoints
- Full operation by an Army flight crew

The flight objectives were achieved successfully although Army crew operation was limited due to erratic pitch and yaw maneuvers. The RPV was recovered successfully after 67 min of flight. A single cycle of a squared "S" search pattern was flown. The pattern had a period of 2.5 km and a width of 1.75 km. The pattern, as shown in Figure 12, had improved but still was [illegible] the desired shape. Additional software smoothing was required and would be [illegible] tested subsequently.

A single loiter pattern with a 0.5 km diameter was flown. The pattern was in the right turn mode. During this pattern the vehicle was very stable, and exhibited none of the erratic flight motions noted in Flight 22, except for a slight yaw perturbation when passing through due north.

During the flight, the RPV experienced several violent short-term pitchup maneuvers. These motions of the RPV caused enough concern that the test director substituted an LMSC RPV operator for the Army trainee. During the postflight inspection, it was found that the accelerometer had excessive hysteresis caused by internal friction.

The automatic retrieval was accomplished successfully by the Army sensor operator trainee, using the 80 series waypoints, after two practice approaches.

3.4.24 Flight 27

Aquila RPV 012 was flown successfully on 14 December 1976. The primary objectives of the flight were to:

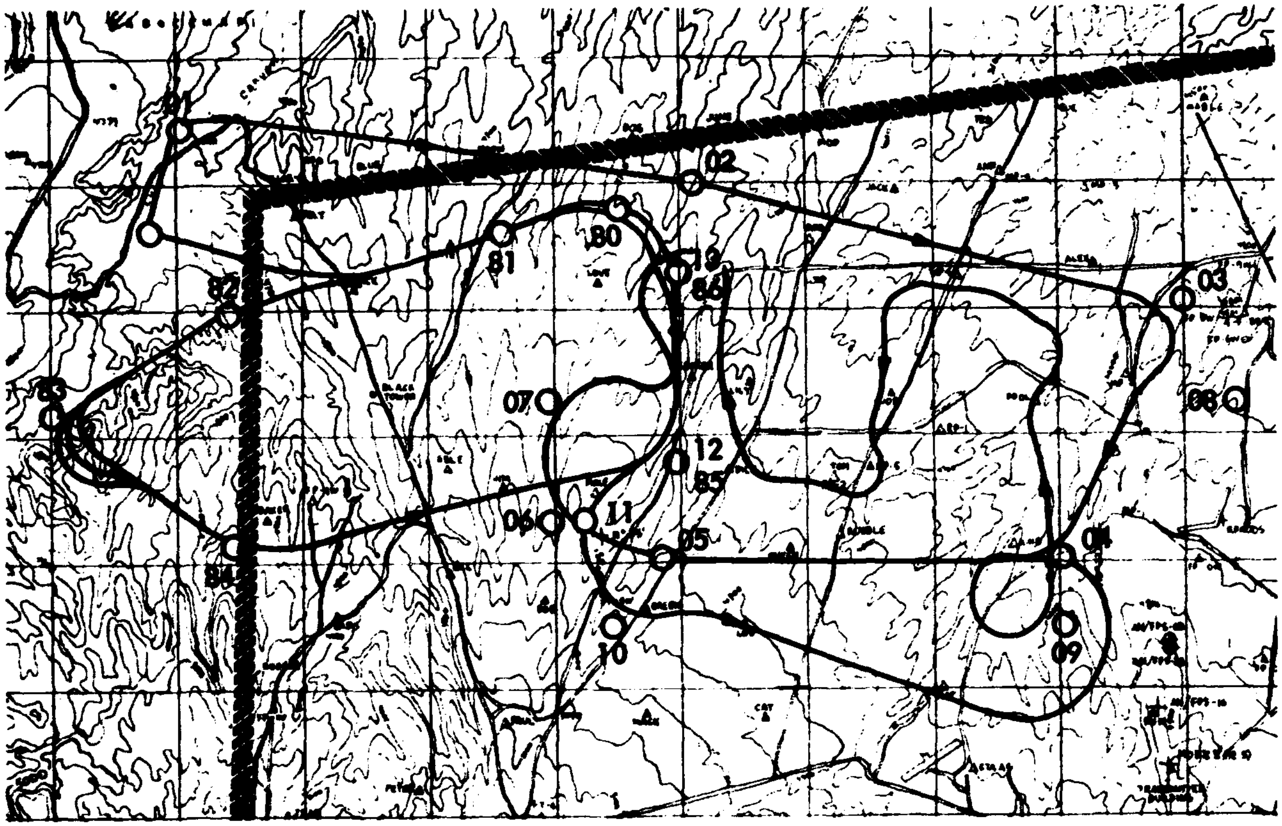

Figure 12. Flight Path, Flight 26

- Demonstrate both the squared "S" and expanding spiral search pattern
- Perform a loiter pattern
- Achieve full operation by an Army flight crew

All flight test objectives were met, and the RPV was successfully recovered after 41 min and 9 sec of flight.

The squared "S" search pattern was flown in a westerly direction for 4 min, 10 sec. The pattern cycle was 2 km with a width of 2.5 km. As shown in Figure 13, the first half of the pattern cycle was irregular. However, the second half showed improvement over previous patterns.

The expanding spiral search pattern was flown for 1 min, 50 sec, in a right turn mode. As shown in Figure 13, this was not sufficient time to complete even one revolution of the pattern. When the RPV was heading due north, it experienced yaw perturbations. These perturbations were not as severe as had been seen in earlier flights while the vehicle was in this mode.

The loiter pattern was flown for 4 min and 35 sec in a right-turn mode. The pattern was 1.12 km in diameter. As with the expanding spiral search pattern, there were slight yaw perturbations whenever the RPV passed through due north. These perturbations were not as severe as seen on Flight 22.

Four practice approaches were made before successful automatic retrieval. This was the first flight totally operated by an Army flight crew.

3.4.25 Flight 28

Aquila RPV 006 was flown successfully on 15 December 1976. The primary objectives of the flight were to:

- Demonstrate system operation to a range of 20 km
- Demonstrate climb performance to 2,740 m (9,080 ft), altitude MSL. The flight path is depicted in Figures 14 and 15.

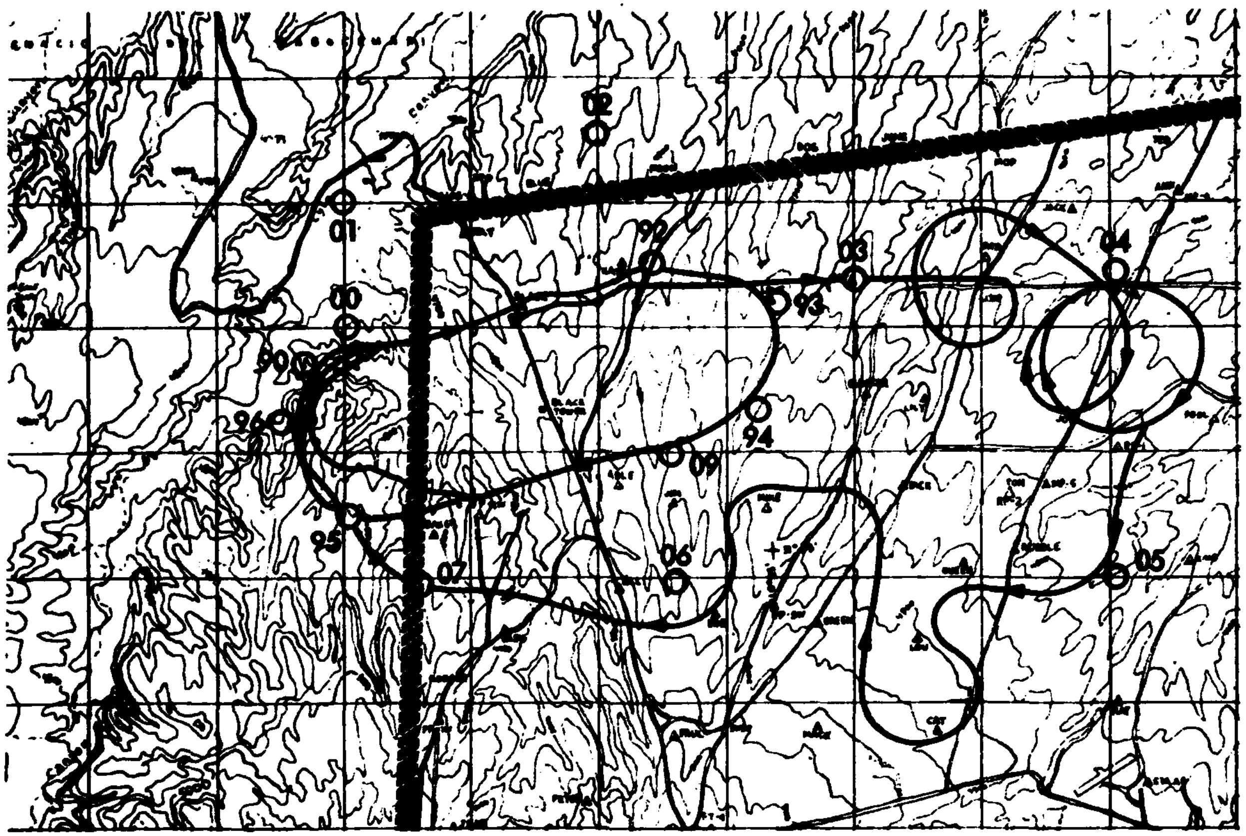

Figure 13. Flight Path, Flight 27

All flight test objectives were achieved and the RPV was successfully recovered after 33 min, 29 sec of flight. During the outbound leg at a range of approximately 11.5 km, the RPV began the same type of roll/yaw cycling that occurred during Flight 23. This action continued until the RPV turned north at waypoint 04. These perturbations did not occur on the leg from waypoint 04 to 05, but started again between waypoints 05 and 06. At waypoint 05, the RPV was approximately 20.2 km from GCS. At this range both the uplink and downlink operated satisfactorily.

The highest altitude reached was 2,684 m (8,800 ft) MSL, between waypoints 06 and 07. At this point, the RPV was climbing at the rate of 90 m/min (300 fpm). Then the RPV was put in a sharp dive toward waypoint 07. The maximum indicated airspeed during this dive was 188 km/h (101 knots), during the initial pitch-down maneuver. Engine rpm at this time was 9,000.

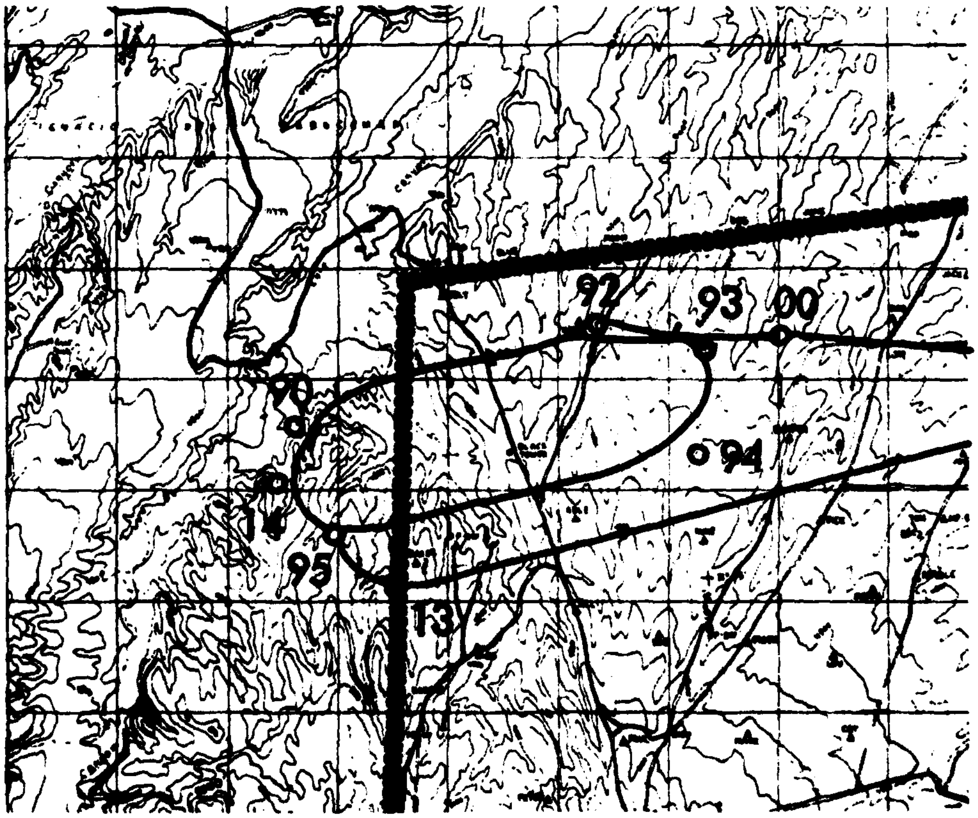

Figure 14. Flight Path, Flight 28 (West Range)

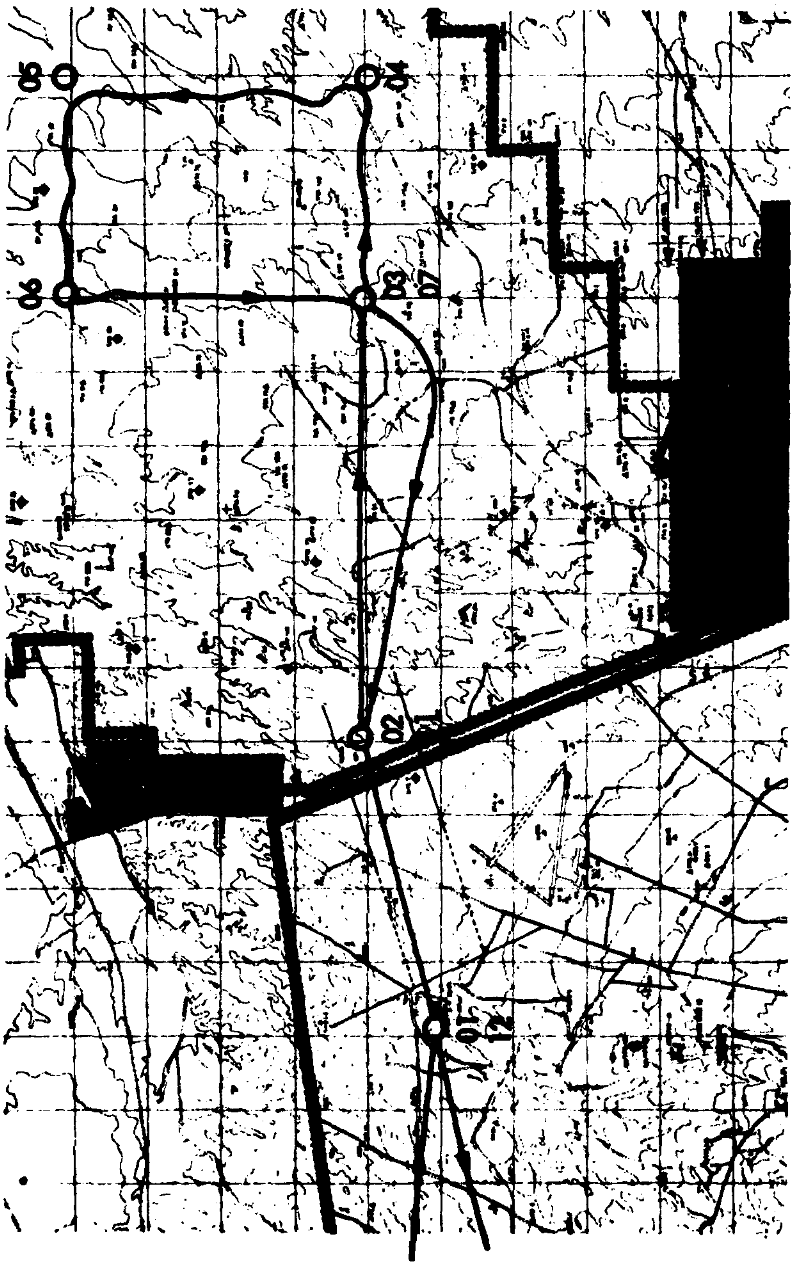

Figure 18. Flight Path, Flight 28 (East Range)

3.4.26 Flight 29

Aquila RPV 012 was flown successfully on 21 December 1976. The primary objectives of the flight were to:

- Perform a loiter pattern
- Perform a squared "S" search pattern
- Determine the ability of the pilot to perform a retrieval utilizing the RPV onboard video camera rather than the ground video camera/cursor combination (the flight path is depicted in Figure 16)

The flight test objectives were achieved and the RPV was successfully recovered after 49 min, 4 sec of flight. RPV automatic launch and waypoint navigation were normal and without anomaly. The RPV entered into a right-hand loiter pattern for 1-1/2 revolutions. As with Flight 27, the RPV experienced slight yaw perturbations whenever the RPV passed a heading of due north. When the search pattern was initiated, the vehicle was beyond the first pattern waypoint, WP 60. As shown in Figure 16, the vehicle executed a 180-deg turn and returned to the correct position. The pattern had a 3-km period and a 3-km width. Two full cycles of the pattern were flown in a westerly direction. The shape of the pattern showed improvement. The only anomaly was an overshoot after completion of a westerly leg.

Three attempts were made to determine the feasibility of achieving vehicle final approach and retrieval utilizing only the RPV onboard video camera. The first two attempts were by the pilot using the manual autopilot mode, and the third by the RC pilot in the stabilized RC mode. To facilitate these attempts, an automobile, with its headlights on high beam, was positioned on each side of the vertical retrieval barrier.

In the manual autopilot mode, the pilot's technique was to hold the commanded IAS constant and to alter the throttle with the altitude thumbwheel. The heading

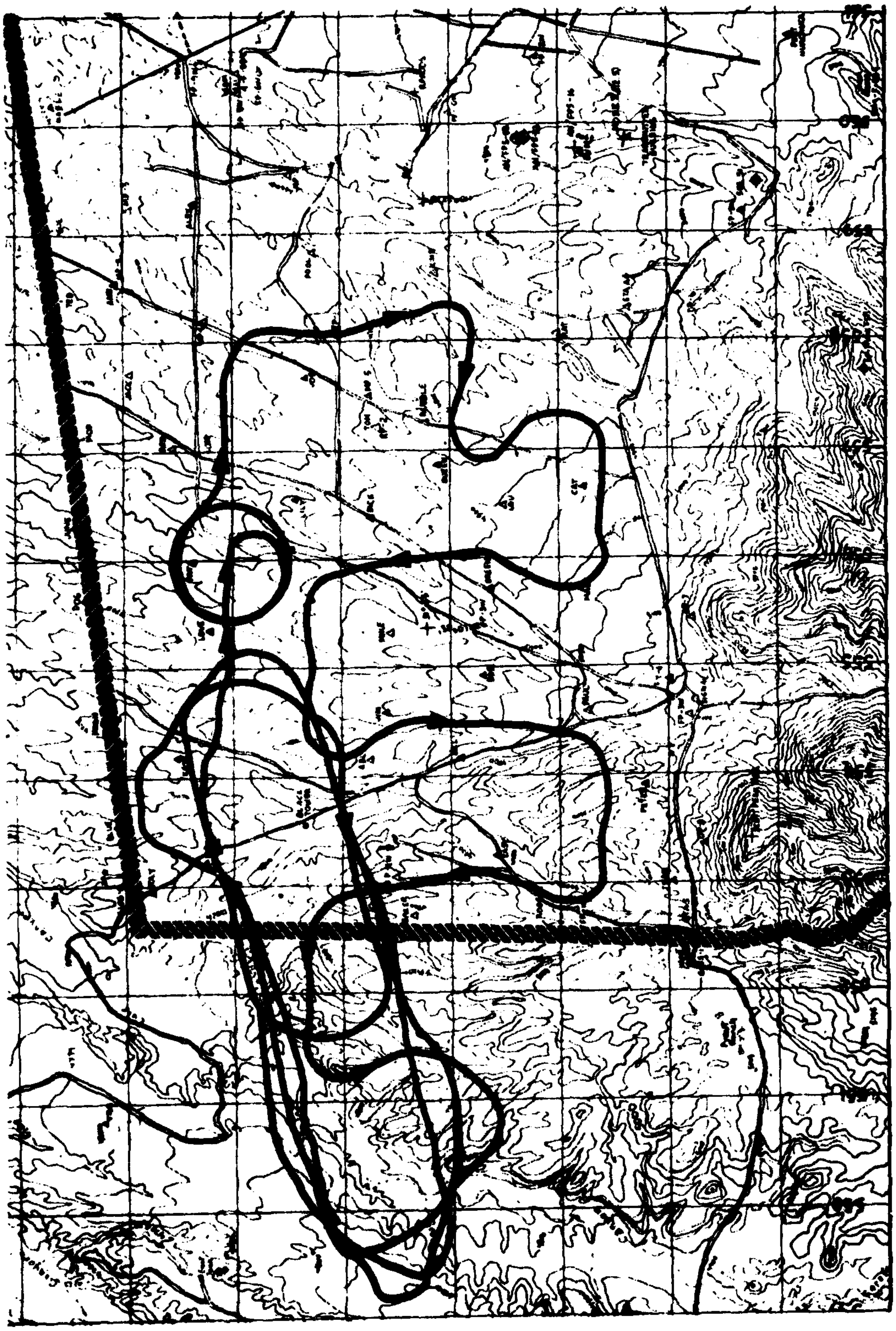

Figure 16. Flight Path, Flight 29

rate trimmer was used for heading commands with the rate command switch in the manual trim position.

A review of the video record discloses that in each attempt the operator first oriented himself relative to the Drone Test Facility maintenance building, approximately 1 km south of the retrieval area. Achieving orientation, the operator then proceeded in the direction of the retrieval area. The first indication of the retrieval area was the sun reflecting off the two vans, which was detectable at about 5 km. Because of the spacing of the vans, their reflections appeared to be the two lights the operator was looking for. Accordingly, the operator would position the RPV in an approach path for the vans. At approximately 2 to 3 km, the actual automobile headlights would become visible. Then, the operator would attempt to reposition the RPV to line up between the headlights. Even though the front wheels of the automobiles were elevated, the automobile headlights were diverted slightly downward. Therefore, as the elevation angle between the headlights and the RPV changed with respect to the ground, the intensity of the lights changed, as viewed by the RPV video. The greater the angle, the less intense the lights appeared. After viewing the video recordings several times, a viewer was able to predict the altitude of the RPV, relevant to the degree approach path, by the intensity of the headlights.

It became apparent that this concept could be used as a backup retrieval method provided that the:

- Approach path is defined independent of known physical landmarks, e.g., Drone Test Facility maintenance building
- Operator is trained as to what he will see and how to fly into the barrier

A quicker orientation by the operator might be achieved if strobe lights were used. It also might help if narrower beam lights were placed beside the ground camera and aimed up the glide slope.

3.4.27 Flights 30 Through 37

Items left unvalidated and problems remaining as of 21 December 1976 included the squared "S" search pattern, the dead reckoning mode, roll/yaw oscillations at ranges in excess of 10 km, evaluation of RPV B engine modifications, development of a standard approach pattern for retrieval, and performance evaluation of hi/lo gain antenna switchover at 5 km. Table 5 lists the objectives and accomplishments for Flights 30 through 37. These were scheduled during January and February 1977 to complete the Phase A flight test program and to provide an additional training opportunity for the Fort Sill U.S. Army students. The parachute backup recovery system and Sony TV camera were installed in the RPVs used for this series of flights. Table 6 is a summary of the objectives, performance, and anomalies associated with those flights. The details of each flight are contained in the following paragraphs.

TABLE 5. FLIGHTS 30 THROUGH 37 – OBJECTIVES AND ACCOMPLISHMENTS

	Flight							
Objective	30	31	32	33	34	35	36	37
Software change evaluation								
Squared "S" search			●			●		
Dead reckoning/heading hold		●			●		●	
Roll/yaw oscillations		●	●		●			●
Standard approach pattern						●	●	●
Hi/Lo gain antenna switchover at 5 km					●			●
RPV change evaluation								
New carburetor shaft	●	●	●	●	●	●	●	●

● Objectives accomplished

TABLE 6. SUMMARY OF FLIGHTS 30 THROUGH 37

Flight No.	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
30	1-19-77	013	43	19	Sony	• Army operator training • Climb and descent rates at 90 km/h for the USAEPG • Waypoint navigation • Waypoint loiter • Spiral search	• Climb rate was 472 fpm, descent rate was 205 fpm at density altitude of 7,000 ft • Waypoint navigation and loiter OK; spiral search OK • Crew performance OK	• Magnetometer failed in flight • Approaches to WP 90 and 91 not consistent	None
31	1-26-77	013	52	21	Sony	• Army operator training • Dead reckoning/heading hold check • Roll oscillation check with 0.5-sec sample rate on heading rate filter at 15-km range	• Dead reckoning performance unacceptable • Roll oscillations not improved • Waypoint navigation and manual autopilot OK • Data link OK at 15-km range • Crew performance OK	• First dead reckoning leg OK; software error prevented remainder • Autotrack antenna slewed around 180 deg during final approach abort and broke track (RPV was between GCS and net)	None
32	1-28-77	012	47	21	Sony	• Army operator training • Square wave search pattern software evaluation • Roll oscillation check at 18-km range	• Data link OK at 18 km and 1,100 ft AGL • Autotrack performance OK • Square wave search pattern acceptable • Crew performance OK	• RPV airspeed varied from 90 to 100 km/min • Roll oscillations beyond 12-km range	None
33	2-2-77	013	52	21	Sony	• Army operator training	• Launch with 11 knot headwind caused steep pitch-up to reduce airspeed • Stall warning indicator performed as designed. • Waypoint and manual autopilot performance OK	• Airspeed undershot commanded by 4.5 knots during pitch-up • Status link losses after launch due to sidelobe lock-up • Broke autotrack during practice final approach abort • Recovery net right lower snubber cable bound-up during retrieval due to moisture	• Right wing tip and wing damaged slightly when wing slipped through horizontal straps and impacted ground

TABLE 6 (Cont.)

Flight No.	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
34	2-8-77	013	53	24	Sony	• Dead reckoning navigation check • Waypoint navigation • Data link at 18 km • Army operator training	• Launch with 4-knot tailwind caused shallow climbout • Time of dead reckoning legs OK • RPV heading integrator initially saturated • Good waypoint navigation accuracy • Good altitude control	• Roll oscillations beyond 9-km range • Dead reckoning headings unsatisfactory due to software sine/cosine of heading rate error and saturated integrator	• Nose cap dented
35	2-11-77	011	53	24	Sony	• RPV-011 check flight • Evaluate 1 by 2 km standard approach pattern • Army operator training	• Waypoint navigation OK • Autotrack OK • Loiter pattern OK • Square wave 2 by 4 km search pattern OK • Spiral search OK • RPV flightworthy • Final approach abort to WP 80 OK	• First approach too low • Altitude below that programmed throughout flight • Altitude error light remained off	• Nose cap slightly cracked
36	2-18-77	013	42	27	Sony	• Dead reckoning/heading hold check • Army operator training	• Dead-reckoning/heading hold performance OK • RPV heading integrator initially saturated • Autotrack on final approaches OK	• RPV launched with autotrack antenna locked on sidelobe; required manual slew	None
37	2-23-77	012	44	28	Sony	• Evaluate version 28 software and roll oscillation effects	• Roll oscillations slightly improved	• RPV airspeed varied from 85 to 110 km/h; pitot line restriction subsequently found • Waypoint turns overshoot increased	• Transmitting (upper) antenna broken off during recovery • Left wing tip cracked slightly

3.4.28 Flight 30

Flight 30 was flown on 19 January 1977 with RPV 013 and Version 19 software. The primary objective of the flight was student training. Because there were no LMSC flight test requirements for this particular flight, the USAEPG requested that climb and descent rate checks be made at a 90 km/h airspeed. The resultant data indicated a climb rate of 472 ft/min and a descent rate of 205 ft/min at a density altitude of 7,000 ft. These numbers are representative of the RPV performance. The mission was planned on the west range primarily as a waypoint mode flight with waypoint path loiter and spiral search patterns and some manual autopilot flying included. All automatic functions performed well during the 43-min flight; however, the RPV magnetometer failed and the heading display ceased. A spare unit was installed after the flight, and it operated properly during subsequent flights.

3.4.29 Flight 31

Objectives were to continue student training, to check the dead reckoning/heading hold mode, and to evaluate the "roll oscillation problem" at a 15-km range with a 0.5-sec sampling rate for the heading-rate filter. RPV 013 was flown on 26 Jaunary 1977 to a range of 15.5 km over the east range. Total flight time was 52 min. The wobble problem was not improved by merely increasing the sampling rate from 1 to 0.5 sec; therefore, it was concluded that additional software changes were required. During the dead reckoning mode test, the RPV flew the first leg properly but failed to turn toward the second leg. A software error was found to be the cause of that anomaly. The automatic launch, automatic and manual flight and semiautomatic recovery portions of the system functioned properly. During the last practice final approach and planned abort, the RPV drifted between the net and the GCS, resulting in the autotrack antenna slewing around 180 deg, and causing subsequent downlink rf problems. This

situation ultimately resulted in a software change which vectors the RPV away from the GCS after an abort from the final approach mode. Recovery of the RPV was normal and there was no damage to the RPV.

3.4.30 Flight 32

Continued student training, improved squared "S" search pattern tests, and evaluation of the downlink antenna polarization (roll oscillation) problem at extended range were the key objectives of this flight. Flight 32 with RPV 012 was flown on 28 January 1977 for 47 min over the east range to a distance of 18 km and at an altitude of 1,100 ft AGL. Heading oscillations along the east-west legs beyond 12 km range were present. The 1-km squared "S" search pattern was improved by a software change and appeared on the plotters to be square with rounded corners. All system elements performed well from launch to recovery. The data link and tracking systems performed well; however, the RPV experienced difficulties maintaining a steady airspeed of 92 km/h. It varied from 90 to 100 km/h throughout the flight. Postflight checks of the airspeed system found no anomalous performance.

3.4.31 Flight 33

The objective of Flight 33 was to continue the training of Fort Sill students. RPV-013 was flown on 2 February 1977 over the west range to a distance of 7 km. The autotrack antenna was locked-up on a side lobe on the launcher and required manual slewing to regain the main lobe after launch. Climbout was steep due to a strong headwind and the STALL indicator was on for 3 sec. The RPV system performed well in the waypoint and manual autopilot modes. Total flight duration was 52 min with three practice final approaches with planned aborts. On two of the approaches to the outer marker, while the crosswinds were 18 to 20 km/h from 220 deg (65 deg across the net), the RPV was buffeted along the track such that the spatial position for engagement into the final approach mode was marginal. During one of the practice approaches and flybys of the GCS, the antenna lost track with the RPV and required manual slewing.

3.4.32 Flight 34

The objectives of Flight 34 were to evaluate the dead reckoning navigation mode, to evaluate waypoint navigation and data link performance at a range of 18 km and to continue training of Army students as system operators. RPV 013 was launched on 9 February 1977 with an 8 km/h tailwind, which occurred late in the countdown. Therefore, the climbout was shallow because the autopilot directed the RPV to increase relative airspeed to that which was commanded. This launch contrasted with Flight 33, where a strong headwind existed and the RPV climbed sharply to reduce relative airspeed to that which was commanded. Beyond a range of 9 km, roll/yaw oscillations (wobble) occurred when the computer commanded ±6 deg/sec heading command changes. This occurs because of a -15 dB depression in the video/telemetry antenna pattern whenever the RPV heading look angle to the GCS is at 180 deg. The dead reckoning navigation check was not completely successful because of a software error, which inverted the sine and cosine of the heading commands. The RPV, however, responsed within 2 deg of the erroneous heading commands. Time durations of the three dead reckoning legs were acceptable. An overshoot of magnetometer heading during the first 20 sec of DR was due to initial saturation of the heading integrator. Later, an integrator shunt was added as part of the B Mods to the flight control electronics package to correct this problem.

Change of the GCS antenna azimuth bias angle significantly improved navigation accuracy. The system produced position accuracy of 40 m, except when the RPV to GCS look angle is along the narrow 15 dB depression (180 deg) in the video/telemetry antenna pattern.

The mean altitude error was -11 m with a 6 m, 1-σ variation. If the roll rate commands are limited to 3 deg/sec, the mean altitude error is expected to decrease to -6 m with a 4.5 m, 1-σ variation. Part of this error is due to side slip effects on the static pressure port readings during the periods of roll/yaw.

Reduction in roll rate will, in turn, reduce this error. The altitude measurement control capability demonstrated by this flight indicated that RPV-013 is capable of meeting system altitude measurement and control requirements. Total flight duration was 53 min.

3.4.33 Flight 35

The objectives of Flight 35 were to perform a check flight on RPV 011, to evaluate the 1-km by the 2-km approach pattern, and to continue training of Army operators. This was the first flight of RPV-011 since it had been repaired as a result of the parachute descent of Flight 19. Mission was flown on 11 February 1977 and flight duration was 53 min to a programmed range of 6 km. Two loiter patterns, a spiral search pattern, and a 2- by 4-km squared "S" search pattern using the 60-series waypoints were accomplished successfully. Waypoint navigation and autotracking were satisfactory. The first pattern at the net was too low and final approach was not entered. The abort mode was selected at a range of 300 m, thereby commanding the higher altitude of WP 80. During this maneuver, the RPV narrowly missed a retrieval net pole. The altitudes of WPs 81 and 82 were adjusted higher by 15 m, and the subsequent four practice final approaches were satisfactory. Throughout the flight, the altitude readout in the GCS of RPV altitude was lower than programmed for the flight; however, the altitude error light remained off. RPV 011 was never flown again and post-flight suitcase check of the vehicle was not accomplished. Therefore, the altitude anomaly was not explained.

3.4.34 Flight 36

Flight test objectives of Flight 36 were to evaluate dead reckoning navigation system performance after the sine/cosine software error had been corrected, and to continue training of Army system operators. RPV-013 was flown on 18 February 1977 to a maximum range of 5 km for a total flight time of 42 min.

The RPV dead-reckoning navigation was satisfactory. The RPV operator initiated the dead-reckoning mode 400 m before the intended waypoint, and the heading integrator was saturated due to the bias problem discussed in the Flight 34 section. These factors caused the actual dead-reckoning flight path to deviate from the planned path. Data analysis revealed that the preprogrammed waypoint locations did not allow the operator to enter the dead-reckoning mode at the proper coordinates. Flight stability and timing along each of the three dead-reckoning legs was satisfactory. On completion of the third leg, the RPV exited the dead-reckoning mode automatically.

3.4.35 Flight 37

The primary objective of Flight 37 was to evaluate Version 28 software changes made to improve the roll stability problem at longer ranges. RPV-012 was flown on 23 February 1977 to 18.5 km over the east range on a 44-min flight. Some improvement was noted beyond a range of 12 km; however, overshoot during waypoint *turns* increased. RPV airspeed fluctuated from 85 to 100 km/h throughout the flight. This was the same problem reported on the last flight of RPV 012 (Flight 32). During postflight checks, a restriction was found in the pitot line between the port and airspeed transducer. The problem no longer was present on Flights 39 and 41.

3.5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This section compares the objectives and accomplishments of Flights 14 through 37 of the Phase A flight test program at Fort Huachuca. Elements of the system were tested, evaluated, demonstrated, and validated during this phase of the program. Upon its conclusion, certain changes were defined as mandatory prior to initiation of the Phase B flight tests with sensors. Those changes were verified during April 1977 flight tests on modified "A" model Aquila RPVs (Flights 38 through 41).

3.5.1 Launcher System

After the launcher incident prior to Flight 14 (as detailed in Appendix B of Reference 2), the launcher system operated nominally on all flights. The only configurational change made to the system after the incident was the addition of rollers on the RPV skeg to reduce brinelling. This change was incorporated for Flight 24 and succeeding flights. Table 7 is a summary of the RPV air speed and pitch rate after each launch for the launches performed in the automatic mode.

At the conclusion of the Phase A flights, several improvements were deemed necessary for incorporation into the launch system prior to start of the Phase B flights. Those "B" modifications were:

- Starter assembly retractor lock
- Permanent and remote ground cooling disconnect
- Remote electrical disconnect umbilical
- Shuttle redesign
- Velocity counter improvement

A more complete description of these changes is given in Appendix C to this volume and Volume II, Section 5.3, Launcher System Evolution.

3.5.2 Retrieval System

After the replacement of the arrester line retrieval system with the vertical barrier system for Flight 15 and succeeding flights, there were no flight failures attributed to the retrieval system. Figure 17 shows the accuracy of the RPV impact of the vertical barrier net, relative to the cursor calibration point, as viewed by the sensor operator for flights with automatic retrieval.

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(2) Lockheed Missiles & Space Company, Inc., Aquila RPV System Test Report, CDRL AOOD, RPV-GCS Development Flights, LMSC-L028081, Part 8, Sunnyvale, Calif., Oct 1977

TABLE 7. SUMMARY OF RPV AUTOMATIC LAUNCHINGS[a]

Flight	RPV S/N	RPV True Airspeed[b] (km/h)[c]	RPV Max. Pitch Rate Off Launcher (deg/sec)
17	011	86.4 (46.6)	+22
18	011	94.8 (51.2)	+24
19	011	86.3 (46.6)	+30
20	006	100.6 (54.3)	+17
21	006	97.2 (52.4)	+18
22	006	98.2 (53)	+14.5
23	006	101.9 (55)	+19.5
24	006	97.4 (52.6)	+17
25	012	96.6 (52)	+30
26	012	95.6 (51.6)	+24
27	012	97.2 (52.4)	+30.5
28	006	96.4 (52)	+28
29	012	96.4 (52)	N/A

(a) All launchings were at a launcher pressure of 270 psig.
(b) Data from RPV air speed system.
(c) Numbers in parentheses = knots.

3.5.3 Air Vehicle Performance

RPV airspeed (in straight and level flight) and rates of climb and descent data with and without the drag brake deployed was obtained on Flights 16, 17, 18, 20, and 28 with RPVs 006 and 011 under controlled conditions. Figures 18 through 24 summarize the performance characteristics of those flights. These data were used with subsequent flight test data in determining the true Aquila RPV performance region.

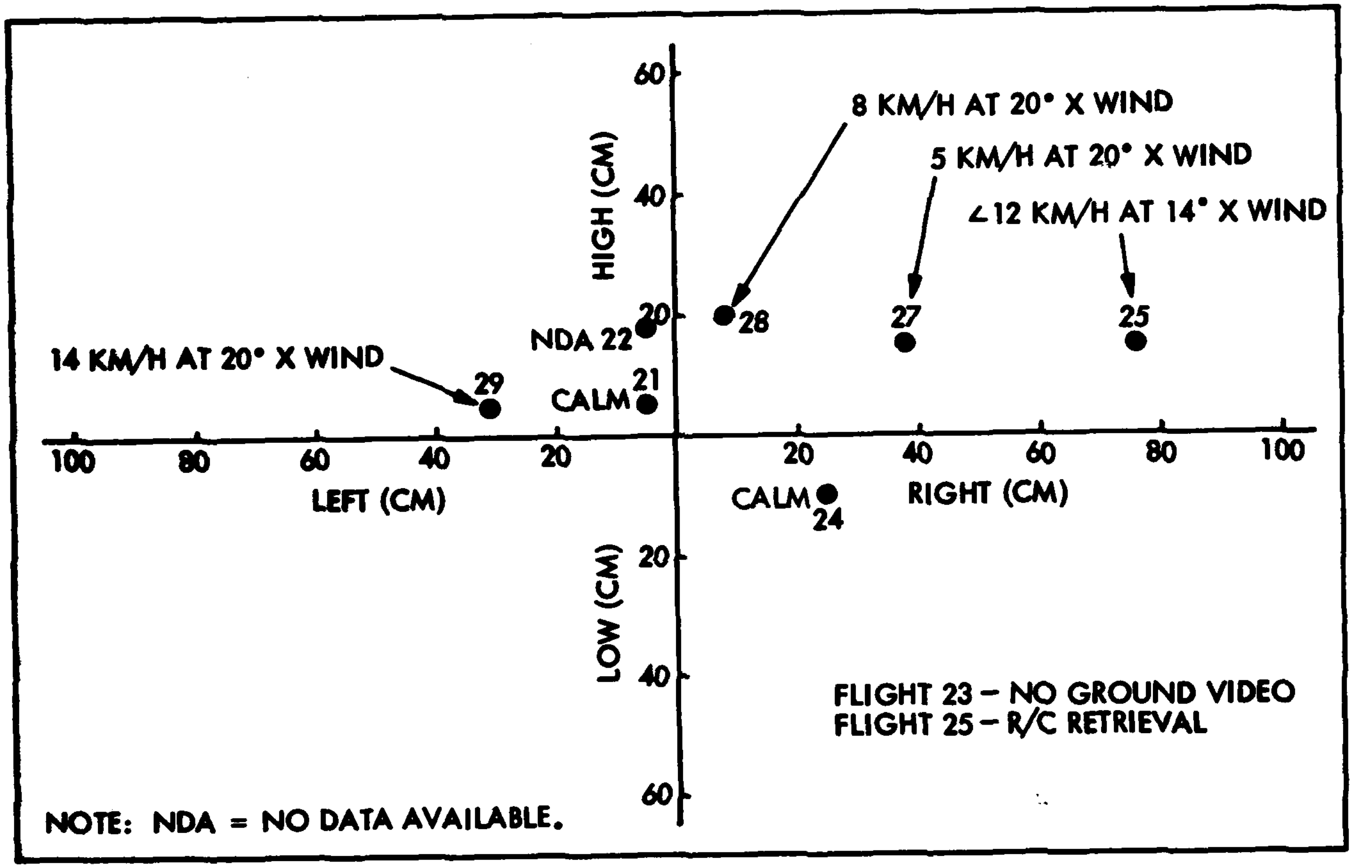


Figure 17. Automatic Retrieval Accuracy (View From Ground Camera)

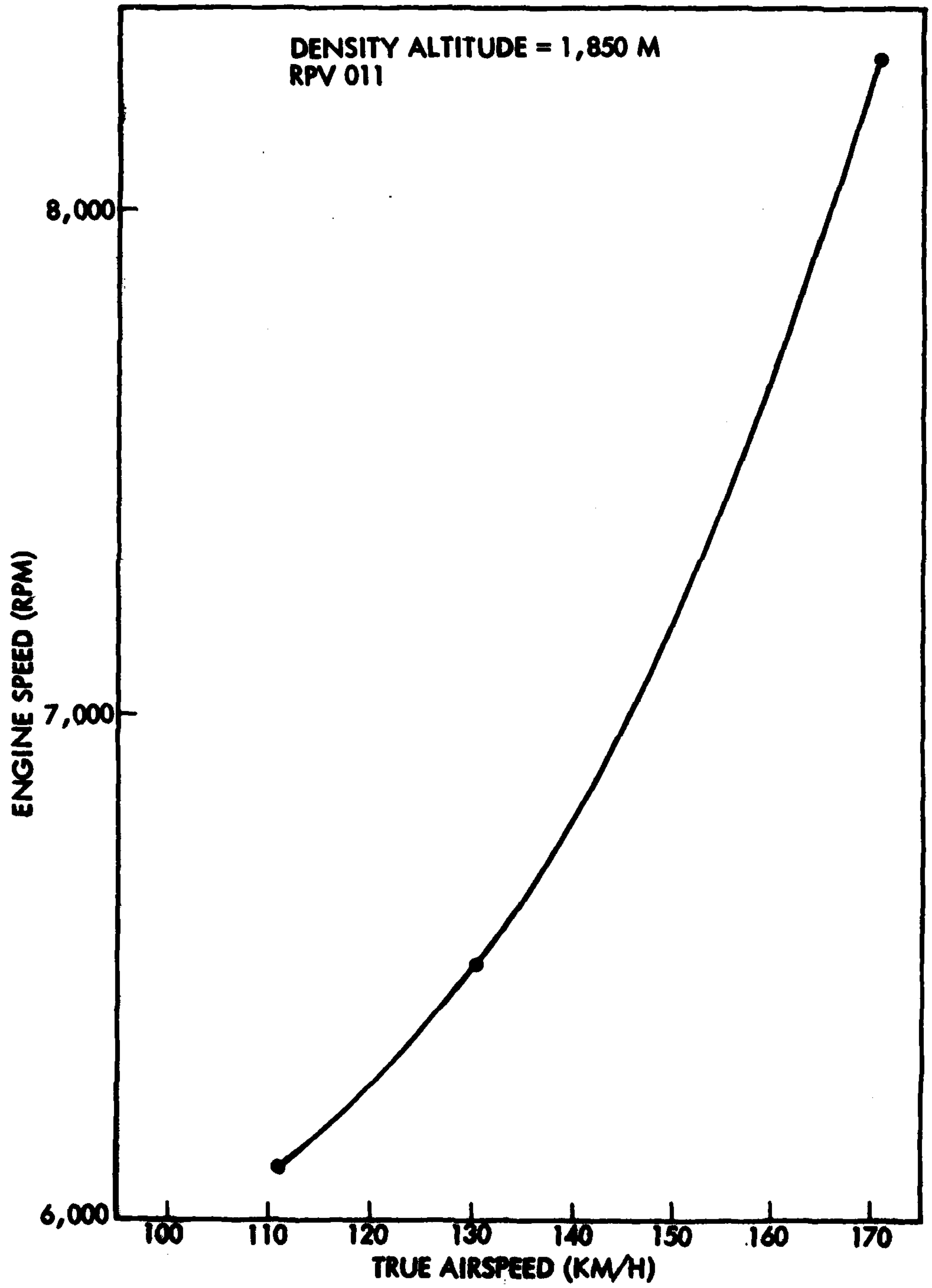


Figure 18. Airspeed vs. Engine RPM (Density Altitude = 1,850 m) RPV 011

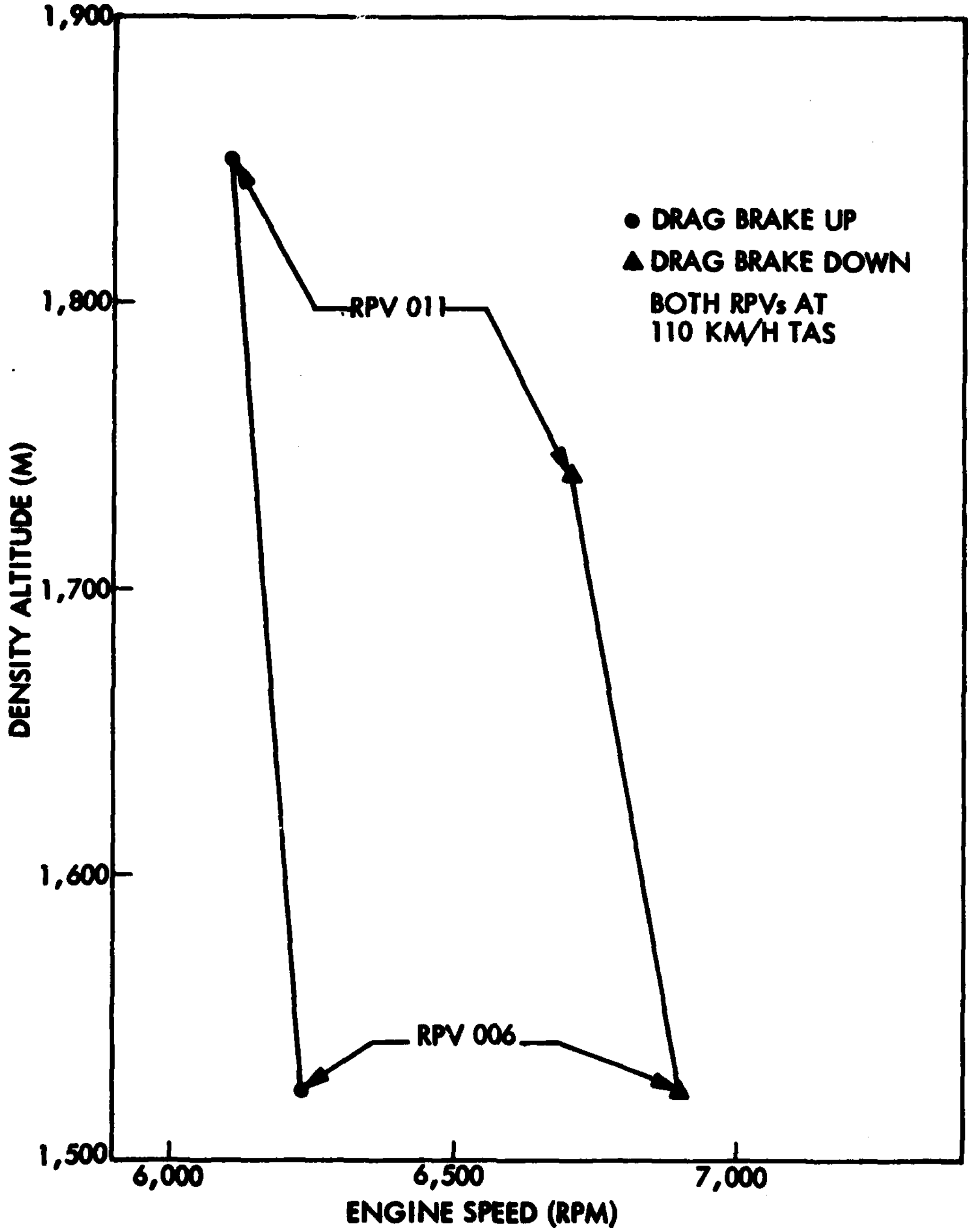


Figure 19. Effect of Altitude on Engine RPM (Level Flight)

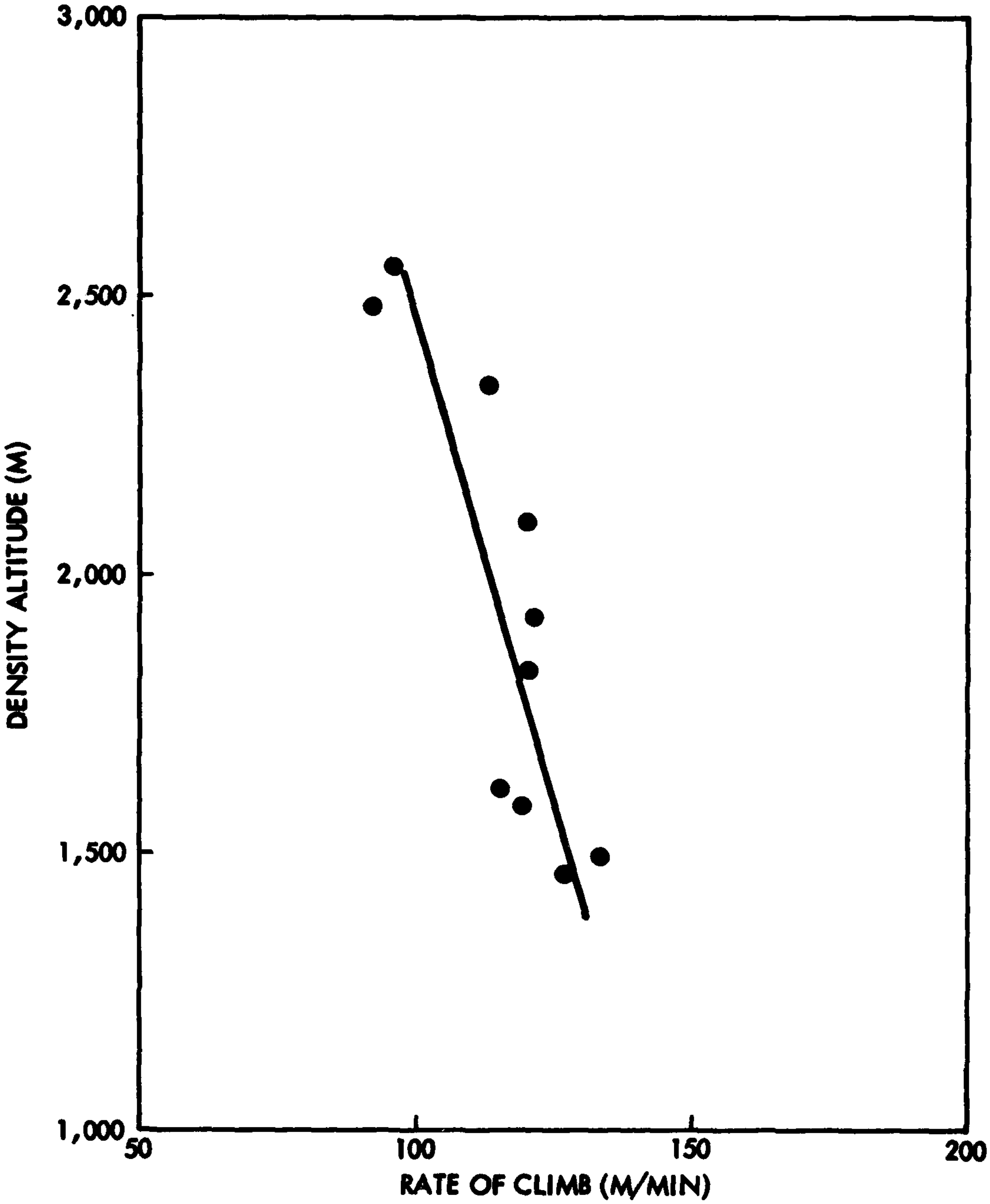


Figure 20. RPV 006 Rate of Climb (100 km/h TAS)

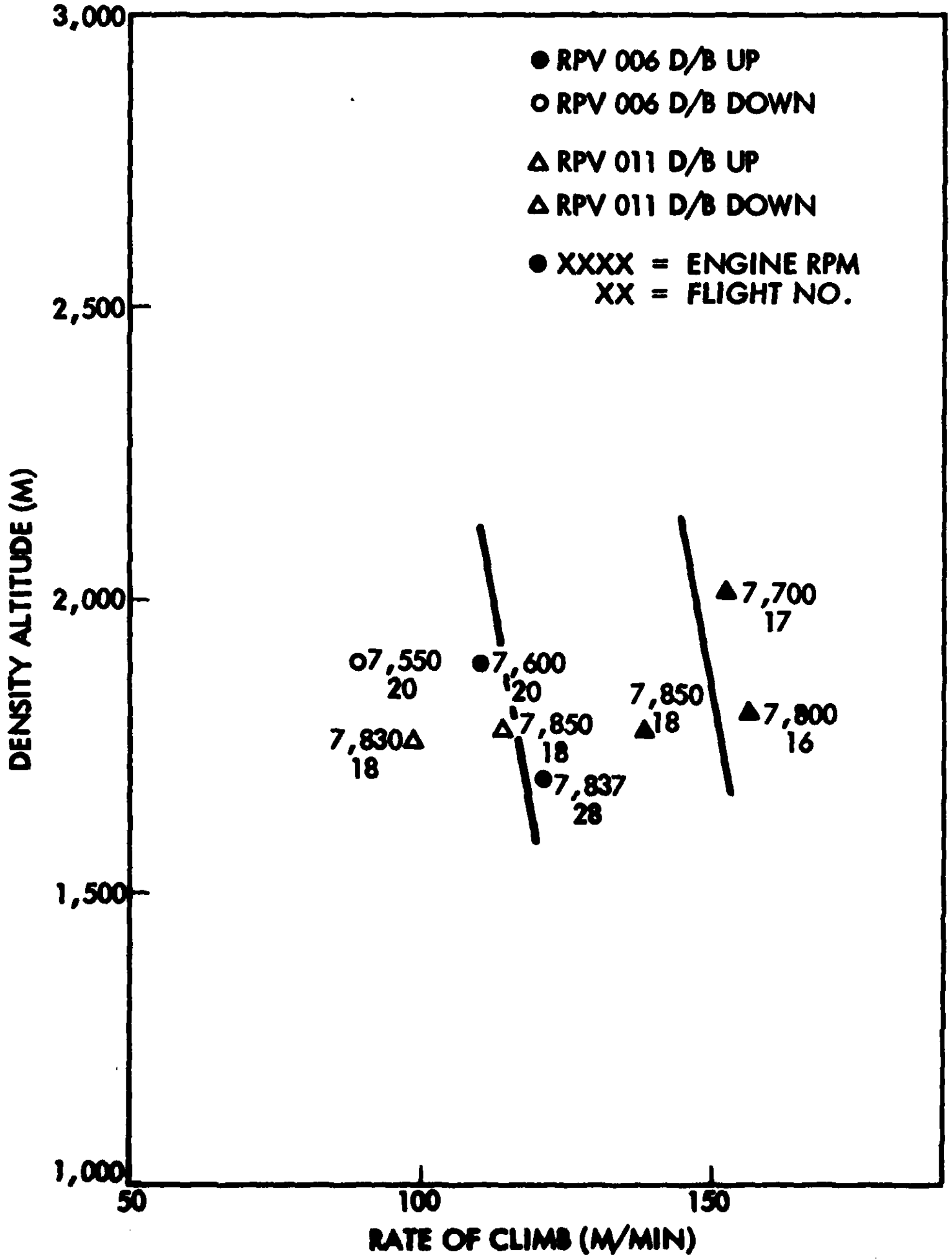


Figure 21. RPV 006 and 011 Rate of Climb (110 km/h TAS)

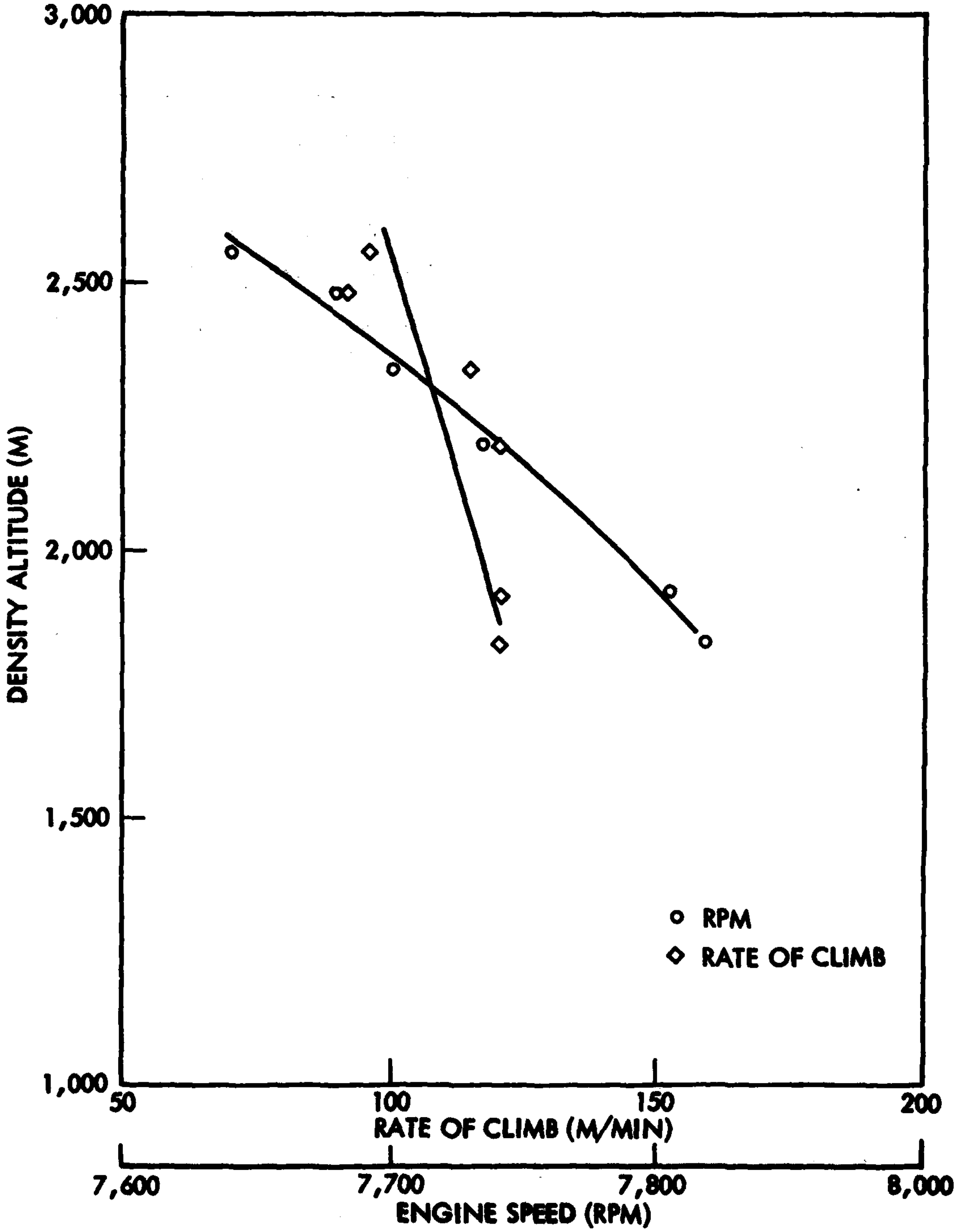


Figure 22. RPV 006 Rate of Climb and RPM (Constant 103 km/h TAS)

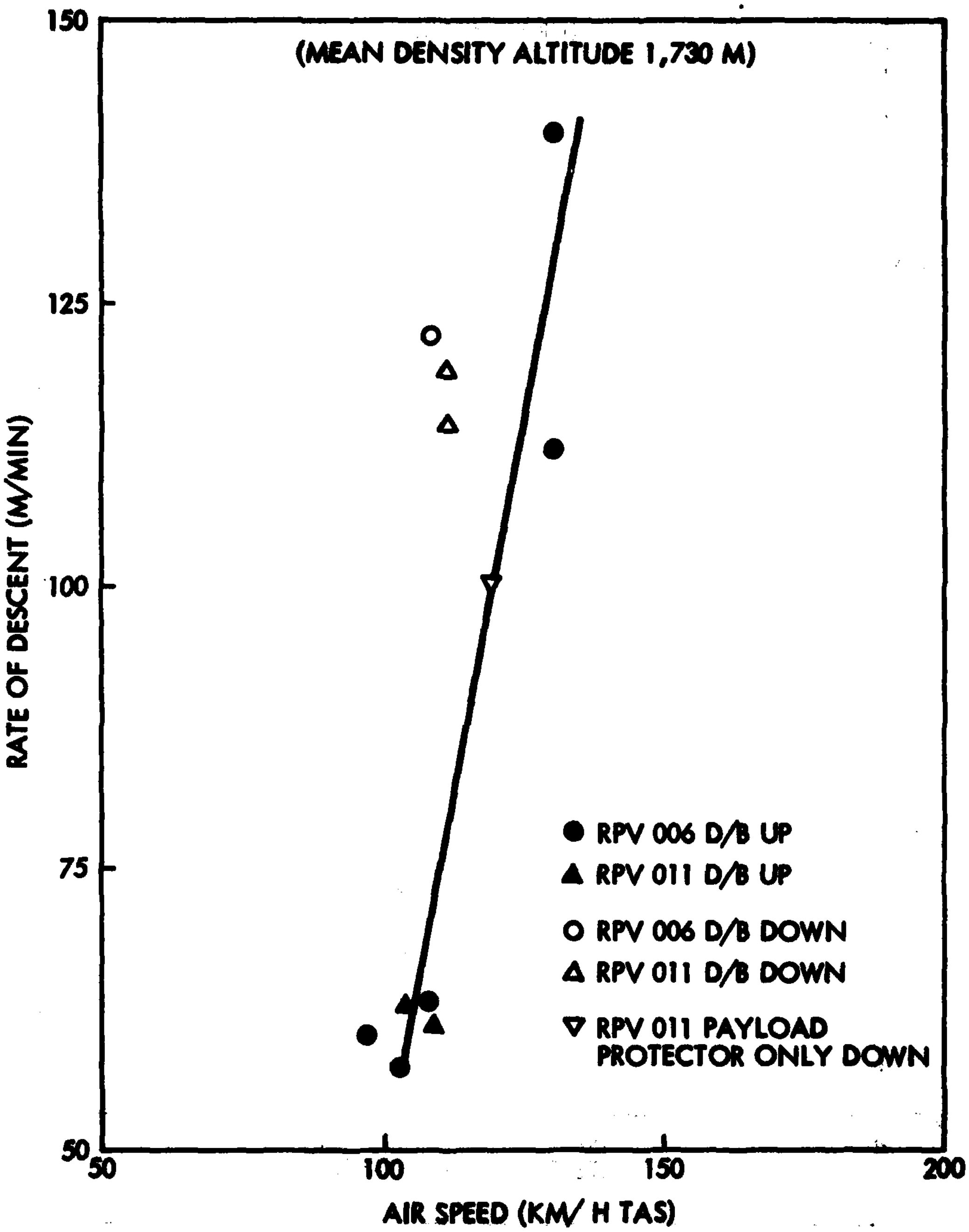


Figure 23. Rate of Descent, RPV 006 and 011, Idle RPM (Mean Density Altitude = 1,730 m)

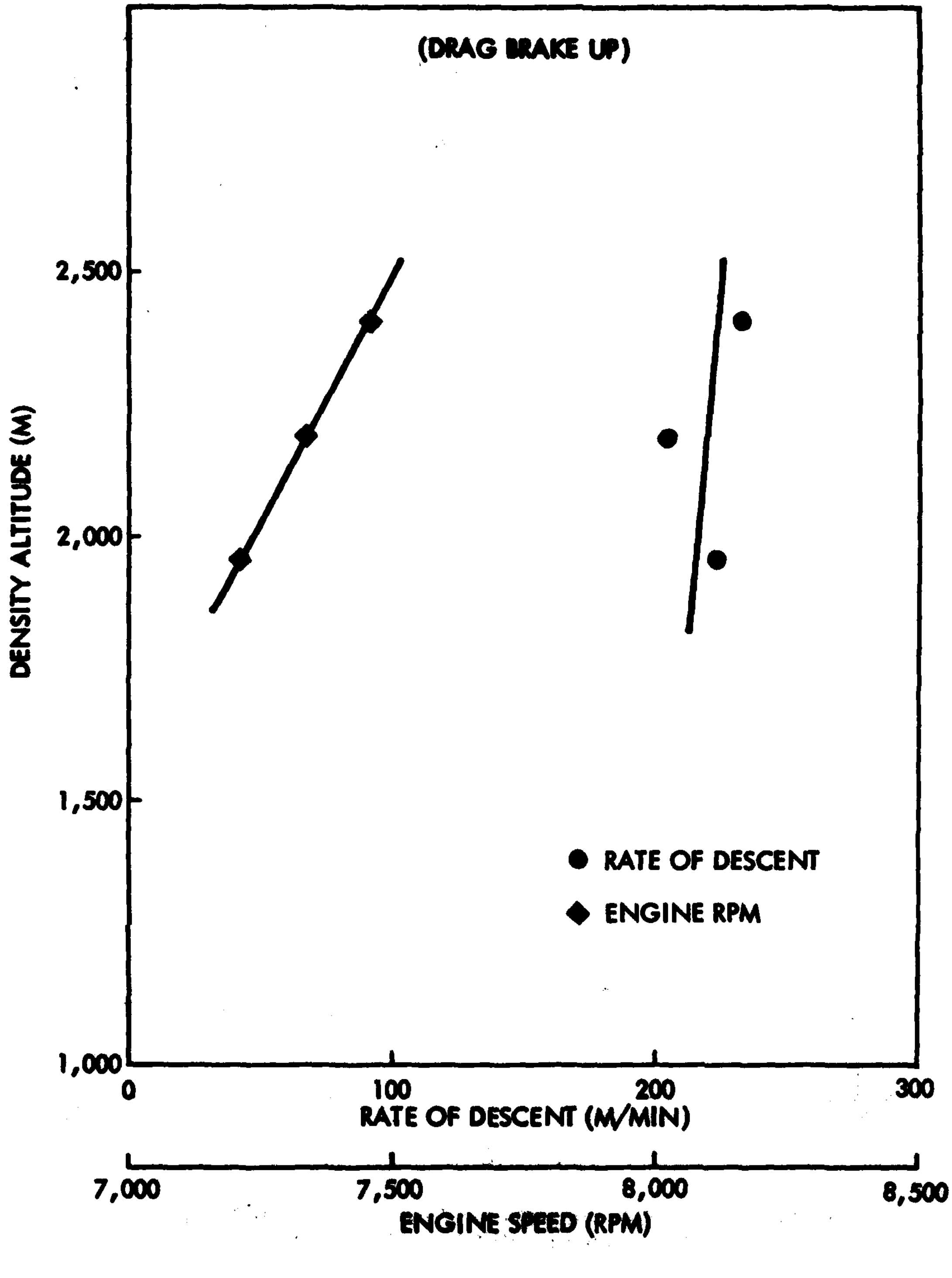


Figure 24. Rate of Descent and Engine RPM, RPV 006 (173 km/h TAS) (Drag Brake Up)

At the conclusion of the Phase A flights, several improvements were deemed necessary for incorporation into the air vehicles prior to start of the Phase B flights. Those "B" modifications were:

- Relocation of RPV receiver antenna
- Flight control package changes for buffer circuit additions, new accelerometer, surge and static protection, TM rechannelization, final approach improvement and deletion of hook deployment provisions
- Replacement of servo motors
- Replacement of accelerometer
- Finalization of shorting plug
- Finalization of wiring harness
- Redesign of skeg pin
- Adding external test connector
- Deletion of parachute system
- Relocation of tracking beacon
- Remounting command receiver
- Redesigning dual carburetor linkage
- Improving engine alignment
- Adding fuel suction lock

3.5.4 Mission Element Performance

Validation of the various mission functions, with the exception of launch and retrieval systems, was dependent upon validation of the software required for the mission element. The mission elements planned for validation were:

- Waypoint guidance
- Loiter pattern
- Expanding-spiral search pattern
- Squared "S" search pattern
- Moving-box search pattern
- Dead reckoning navigation

3.5.5 Waypoint Guidance

During this phase of the flight test program, the waypoint guidance element performed as programmed with the exception of three instances in which the final approach waypoints had to be adjusted. During these flights, the RPV never failed to respond to waypoint guidance instructions nor did it fail to recognize a waypoint. In fact, on several flights the RPV operator failed to transfer out of the manual mode until after a waypoint or a search initialization point had been passed. In each case, the RPV returned to the missed waypoint and continued on the preprogrammed flight path.

The three instances where the final approach waypoints had to be adjusted were Flights 20, 22, and 35. On Flight 20 the waypoints were judged to be too high; and on Flights 22 and 35, too low. Two factors can cause the RPV not to be at the proper altitude for retrieval. One contributor is a change in the retrieval site pressure altitude from that programmed for final approach. This change is a result of the change in temperature at the Ground Control Station, from the time the waypoint inputs into the computer until the RPV (which flies pressure altitude) enters final approach. The second factor is the least-significant-bit (LSB) range in altitude, both commanded and measured, of 14.3 m (47 ft). The LSB does not remain constant. If the commanded altitude is fluctuating about one of the extremities of the LSB, the RPV position will fluctuate accordingly. The combination of these two factors can result in errors in the final approach position of the RPV. On each of the occasions when altitude adjustment was required, the maximum adjustment was equivalent to two LSB ranges.

3.5.6 Loiter and Expanding-Spiral Search Patterns

These two mission elements will be considered together, because they are derivatives of the same basic software equation. As noted in section 3.4 on Flights 22 and 23, in both modes the RPV experienced a tendency to wander in yaw. These perturbations became greater whenever the RPV was flying due north.

This same phenomenon was repeated at Sunnyvale using the LMSC Guidance Laboratory six-degree-of-freedom analog simulator. The problem was traced back to the software equation. The equation directs the RPV to fly a prescribed radius, either constant or expanding, about a defined waypoint. The equation maintains the prescribed radius by continuously sampling the relationship of the RPV to the waypoint. As with any equation describing a moving radius around its center, at some point the polar angle of the radius must return to its origin. For the loiter and expanding spiral search patterns, this point occurred when the RPV was positioned due north. The equation was changed to require more data points to establish the RPV radial position relative to the waypoint center. This increase in data sampling resulted in a smoothing of the RPV path. This revised software was flown on Flights 26, 27, 29, 30, and 35. The effect of the smoothing was to eliminate all RPV waypoint perturbations except for a very slight tendency of yaw wander at the due north position. This residual yaw motion is not of sufficient magnitude to affect the RPV mission element performance.

3.5.7 Squared "S" Search Pattern

Evaluation of the squared "S" search pattern software was made initially during Flight 24; however, the pattern was not square. Figure 11 shows the "dished-in" sides and rounded ends which were obtained. The software was revised and the pattern reflown on Flights 26 and 27. Figures 12 and 13 indicate some improvement but not to an acceptable level. The software was revised again and the pattern performed on Flight 29. Further improvement was realized but the sides still were not square due to excessive overshoot in the turns. A final revision to that portion of the software produced an acceptable pattern on Flight 32. The sides were square with rounded tops. Therefore, the squared "S" pattern software was validated.

3.5.8 Moving-Box Search Pattern and Dead-Reckoning Navigation

Because of its low priority, the validation of the moving-box search pattern was postponed until the sensor validation flight test phase. Problems in development of GCS and RPV hardware to effect command termination (tone control) of the dead-reckoning mode delayed further testing of this system feature for range safety considerations.

3.5.9 Software

Evolution of the software was a continual task in support of the flight test program. With the resumption of flight testing on 13 September 1976 and the start of Phase A, a software version number was assigned to the master tape. The version number increased with each revision. By the conclusion of the Phase A flight tests with Flight 37, the software was at Version 28. All of the software programs had been validated at that time except for the moving-box search pattern, dead-reckoning navigation, and payload (sensor) functions.

At the conclusion of the Phase A flights, several software improvements and problem resolutions were deemed necessary for incorporation prior to start of the Phase B flights. These "B" changes were:

- Final approach criteria
- Dead reckoning criteria
- Roll/yaw stability improvement
- Computer protection from power failure

3.5.10 Data-Link Performance

Data-link performance was evaluated at close range (0 to 5 km), intermediate range (5 to 15 km), and long range (15 to 20 km). As a result, the data-link system went through two cycles of changes to arrive at the present configuration,

which has been satisfactorily validated. The first major design changes, resulting from the flight tests at Crows Landing, involved data-link system compatibility type changes. The second set of changes resulted from the Phase A testing at Fort Huachuca and was implemented into the hardware prior to the Phase B flight testing. These changes, labeled the "B" changes, were based on a desire to increase the link margin of the data-link system and to improve the tracking performance of the low gain antenna tracking loop. These changes were:

- Antenna couplers
- Antenna wind protection
- Increased command antenna gain
- Improved low-gain tracking
- Tracking antenna scan converter modifications
- Minor lobe locking
- Relocated RPV receiver antenna

Tables 8, 9, and 10 show the link analysis for three data-link versions. A more detailed explanation of the evolution of the data link can be found in Volume II, Section 4.6, Data Link Elements Evolution.

3.5.11 Ground Control Station

By the end of the Phase A flight test program at Fort Huachuca, all of the GCS operational features, except for RPV positioning accuracy and sensor-related functions, had been validated. RPV position accuracy had not been validated because of a discrepancy between GCS tracking data and AN/FPS-16 tracking data and the roll/yaw stability problem. A tracking antenna azimuth pointing error or approximately 1 deg was noted, and the source of the error has not been found. Two possibilities were (1) an error in site layout at Sycamore Canyon, or (2) a misalignment between the optical and rf boresights of the tracking antenna. After completion of the Phase A flights, a sufficient statistical sample of data was derived and a new antenna correction angle was placed in

TABLE 8. LINK ANALYSIS, ORIGINAL DATA LINK

Uplink		
Command Transmitter Power (10 W)	+40 dBm	
Transmit Antenna Gain	+12 dBi	
Space Loss (20 km)	-133 dB	
Polarization Loss	-3 dB	
Airborne Receive Antenna Gain	-10 dBi	
Receiver Sensitivity	-(-65) dBm	
Fade Margin:	-29 dB	
Downlink	**TM**	**Video**
Video Transmitter Power (10 W)	+40 dBm	+40 dBm
Transmit Antenna Gain	-15 dBi	-15 dBi
Space Loss (20 km)	-133 dB	-133 dB
Polarization Loss	-3 dB	-3 dB
Ground Receive Antenna Gain	+24 dBi	+24 dBi
Receiver Sensitivity	-(-76) dBm	-(-82) dBm
Fade Margin:	-11 dB	-5 dB

TABLE 9. LINK ANALYSIS, "A" CHANGES

Uplink		
Command Transmitter Power (10 W)	+40 dBm	
Transmit Antenna Gain	+12 dBi	
Space Loss (20 km)	-133 dB	
Polarization Loss	-3 dB	
Airborne Receive Antenna Gain	-7 dBi	
Receiver Sensitivity	-(-94) dBm	
Fade Margin:	+3 dB	
Downlink	**TM**	**Video**
Video Transmitter Power (10 W)	+40 dBm	+40 dBm
Transmit Antenna Gain	-7 dBi	-7 dBi
Space Loss (20 km)	-133 dB	-133 dB
Polarization Loss	0 dB	0 dB
Ground Receive Antenna Gain	+24 dBi	+24 dBi
Receiver Sensitivity	-(-85) dBm	-(-82) dBm
Fade Margin:	+9 dB	+6 dB

TABLE 10. LINK ANALYSIS, "B" CHANGE FINAL CONFIGURATION

Uplink		
Command Transmitter Power (10 W)	+40 dBm	
Transmit Antenna Gain	+24 dBi	
Space Loss (20 km)	-133 dB	
Polarization Loss	0 dB	
Airborne Receive Antenna Gain	-10 dBi	
Receiver Sensitivity	-(-94) dBm	
Fade Margin:	+15 dB	
Downlink	**TM**	**Video**
Video Transmitter Power (10 W)	+40 dBm	+40 dBm
Transmit Antenna Gain	-7 dBi	-7 dBi
Space Loss (20 km)	-133 dB	-133 dB
Polarization Loss	0 dB	0 db
Ground Receive Antenna Gain	+24 dBi	+24 dBi
Receiver Sensitivity	-(-88) dBm	-(-85) dBm
Fade Margin:	+12 dB	+9 dB

the software program. This position inaccuracy contributor was thereby eliminated, leaving only the roll/yaw stability problem contribution. Prior to start of the Phase B flights, several "B" modifications to the GCS were deemed necessary. Those were:

- Hook and parachute control switch deletion
- Inflight diagnostic panel addition
- Dead-reckoning tone correction
- Second Topaz voltage regulator addition
- Sensor panel improvements
- Waypoint display noise reduction
- Failsafe launch velocity addition
- Intercom buffer and wiring improvements
- Shelter waterproofing

Volume II, Section 4.6, GCS-Data Link Elements Evolution, contains a discussion of GCS related problems and corrective actions.

3.5.12 Procedures

During the course of flight testing, procedures were being updated and improved constantly. At the conclusion of the Fort Huachuca Phase A flight testing, a valid set of procedures was in use by both the LMSC test team and the Army test teams. These procedures covered site setup, prelaunch checkout, flight planning, flight operations, and postflight operations. Discrete procedures related to the sensor validation phase were not included in the procedures but were planned for completion during the Phase B sensor flight test program.

3.5.13 Test Team Training

Using the aforementioned procedures, and additional training aids, the LMSC test and training team provided classroom and OJT to a U.S. Army flight test team from Fort Sill, Oklahoma. The success of this training can best be measured by the fact that this team conducted the final 12 flights of the Phase A test program.

Section 4
PHASE B TESTING – FORT HUACHUCA

The Phase B Contractor flight test program at Fort Huachuca started on 1 April 1977 with Flight 38 and concluded on 10 July 1977 with Flight 65. One air vehicle (RPV-015) was lost due to operational errors. The first four flights were planned primarily as "B" modification check flights to validate some of the more critical changes incorporated into "A" model aircraft. The remaining flights used RPVs 014 through 017, which were the "B" model aircraft. These flights were primarily sensor validation flights but did include objectives associated with resolution of open Phase A problems, validation of the "B" modifications to the Aquila system and qualification/certification of Army crews. The Phase B validation test program was planned for completion by the end of June 1977 and so that the Army flight test programs by the Electronic Proving Grounds and the Field Artillery Board could be completed in a timely manner, a prioritized set of sensor system flight test objectives was developed. Those objectives, ordered below, are shown graphically in Figure 25.

- Army crew qualification demonstration
- Target designation demonstration
- Target location demonstration
- Stabilized sensor and autotrack demonstration
- Artillery adjustment mission demonstration
- Target detection and recognition demonstration with a stabilized sensor
- Target detection and recognition demonstration with an unstabilized sensor
- Photo-reconnaissance mission demonstration

In addition, several Aquila system operational features from the Phase A flight test program remained to be validated. Those were:

- RPV position accuracy
- Dead-reckoning navigation

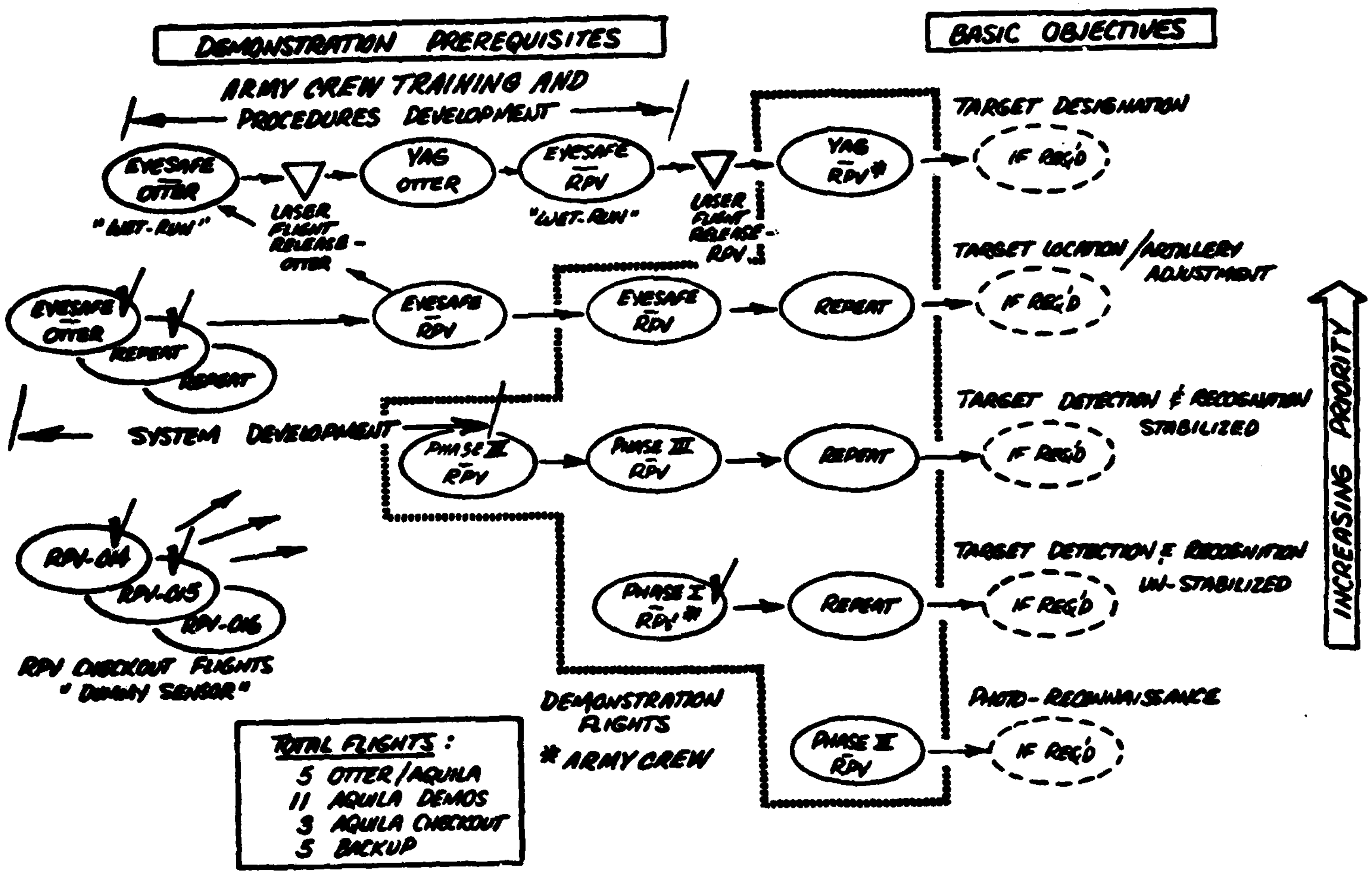


Figure 25. Aquila Series-B Flight Test Objectives, Prerequisites and Priorities

- Moving box search pattern
- Data link at 20-km range
- Cross-wind recovery
- Standard approach pattern
- "B" modifications to the RPVs, GCS, and Launcher

4.1 FACILITY

The Phase B RPV flights were accomplished from the same Sycamore Canyon site used for the Phase A flights. The Phase B program included, however, some sensor and GCS modification check flights with the U-1A Otter aircraft. Additional facilities used extensively during sensor tests were the Spatial Resolution Facility, the Radar Spoke Facility, the East Range, and the Libby Army Airfield taxiway for laser boresighting.

4.1.1 Spatial Resolution Facility

During the Phase B sensor flights, the spatial resolution target on the east range was used for assessing Phase I, II, III, and IV sensor spatial resolution and distortion capabilities. The facility covers a 4-acre area and consists of a flat concrete surface forming three wedges. Each wedge is 678 ft long and approximately 200 ft wide at the open end. Two of the wedges have painted triplet bars for spatial resolution measurements.

4.1.2 Radar Spoke Facility

Also located on the east range is the Radar Spoke Facility, which is normally used to measure the range and azimuth resolution of test radar simultaneously. The radar spoke consists of four arms that meet at right angles. Along each of the four arms are 143 site posts spaced at increasing distances, ranging from 1 m near the apex to a maximum of 512 m at the ends of the arms. This facility was used during the Phase B sensor flight tests because of its known location and geometry and ease of long-range detection. Target vehicles, reflector,

and scoring boards were placed there for evaluating laser hit scoring and GCS readouts of target position and altitude during YAG and Eye Safe laser operations with both the Aquila RPV and the Otter as sensor carriers.

4.1.3 Aquila Otter Configuration

Army U-1A Otter aircraft 92222 was modified under separate Army contract by LMSC to include electronic portions of the Army Aquila RPV system. This configuration permitted Army personnel to operate the Aquila RPV system as though a functional RPV were flying instead of a manned aircraft. Operation of the C-band telemetry data link, payload sensor, altimeter and airspeed transducers, magnetometer, vertical gyro, flight controls electronics package, and other necessary airborne system elements, gave the appearance to the GCS operators that a real Aquila RPV was flying under their command authority. The system elements were arranged in the aircraft as shown in Figure 26. Photographs of major portions of the actual equipment installations in the Otter aircraft are shown in Figure 27.

The pilot's steering indicator, as shown in Figure 26(a), displayed the heading rate commands that are normally fed to the RPV autopilot. In responding to the steering indicator needle commands, the pilot introduced turns to fly the aircraft as commanded by the RPV operators or the GCS computer.

The RPV flight control electronics unit, data-link equipment, and payload sensor equipment were installed in the Otter aircraft as shown in Figure 27(b). The payload sensor installation plate was hinged at the forward edge to allow the sensor to be retracted into the aircraft when not in use or during takeoff and landing operations. Internal and external views of a payload sensor in the extended position are shown in Figures 27(c) and 27(d), respectively.

No changes were made in the Aquila GCS to accommodate the Aquila Otter aircraft system except for relatively minor, but vital, changes in the standard Aquila software. The Otter was generally used as a minimum risk GCS operator training and hardware checkout opportunity. Both flight hardware, GCS

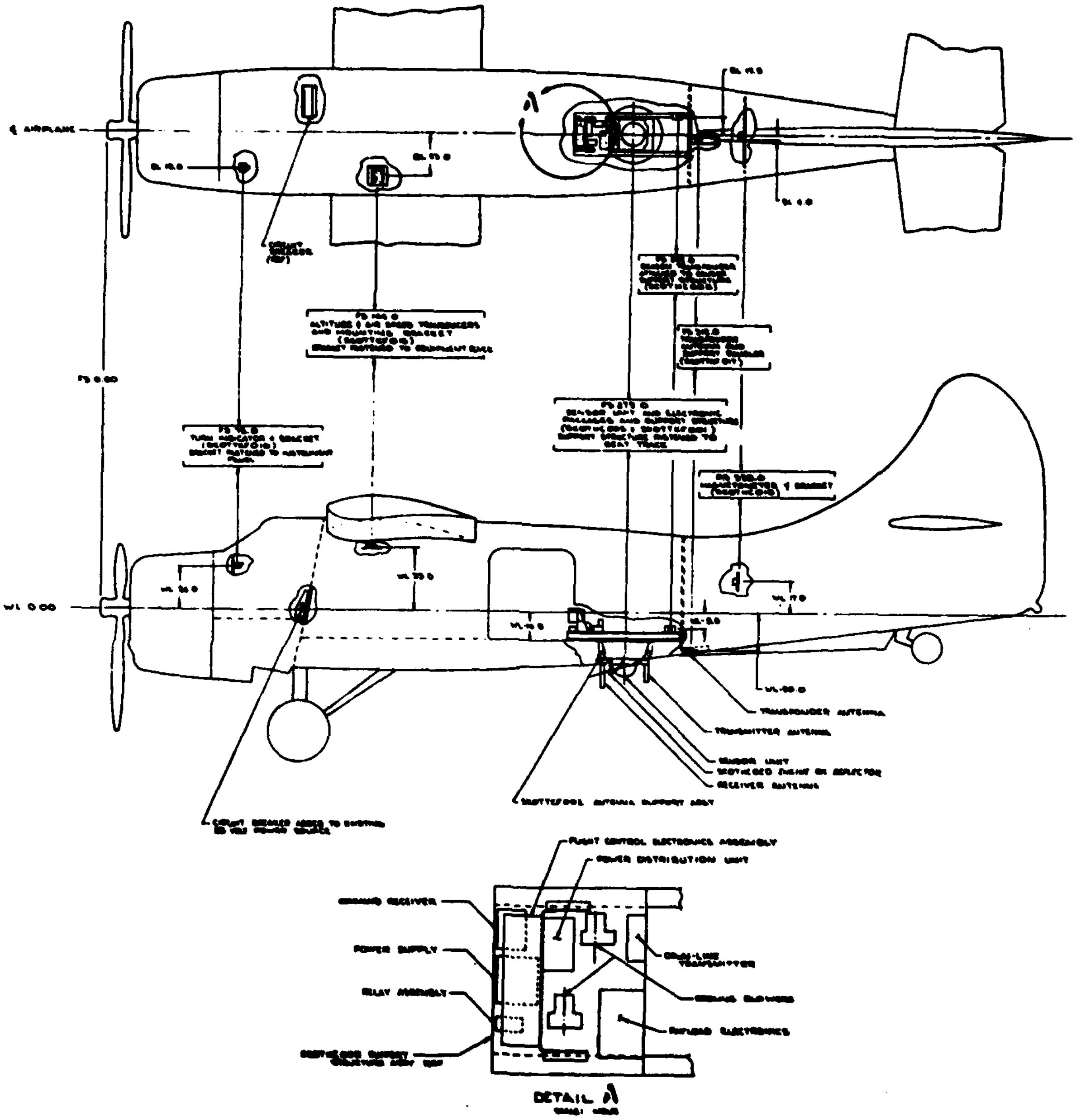
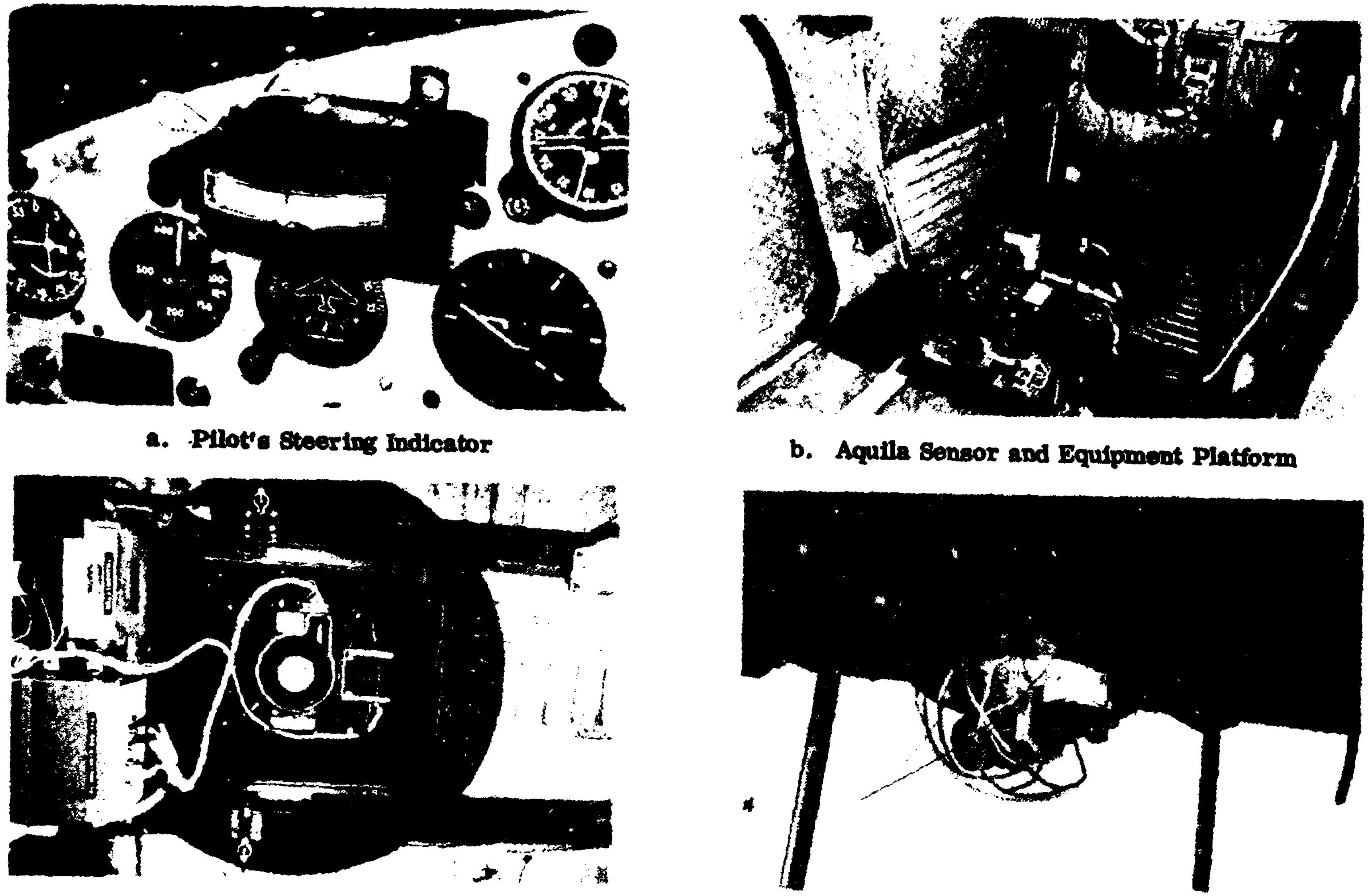


Figure 26. Aquila Otter Equipment Installation Diagram



a. Pilot's Steering Indicator

b. Aquila Sensor and Equipment Platform

c. Top View of Sensor

d. Bottom View of Sensor

Figure 27. Aquila Otter Equipment Installations

hardware, and software could be validated prior to committing the equipment to an RPV flight.

4.1.4 Laser Boresight

Boresighting of the Phases IV and V Eye Safe and YAG lasers was accomplished prior to every RPV and Otter laser designation flight for two reasons. First, it was a requirement of the LMSC prepared range safety plan. Second, the contractor desired to obtain a history of the boresight alignment degradation resulting from the launch, flight, and retrieval environments. As boresight alignment techniques and procedures were improved, the results became more consistent. No degradation in boresight alignment was found as a result of the last few laser designator RPV flights. Alignment adjustments, from necessity, had to be accomplished over a sizable distance. One of the taxi-ways at Libby Army Airfield was generally used for boresight alignment. The LMSC laser scoring board was utilized for this task. This device is an active quadrature detector in the YAG laser wavelength band. Visual annuciators are displayed when the impinging laser energy falls on the respective quadrant. A hand-held laser viewer was also used to verify proper alignment of the TV optics and laser boresight on the score board. Whenever the YAG laser was fired, all crew members were required to wear laser safety goggles. To prevent stray laser energy from leaving the immediate work area, an arrangement of safety baffles was deployed around the sensor. The USAEPG range operations organization provided all safety personnel and equipment for these boresightings.

On several occasions, during the initial checkout of the Phases IV and V sensors, greater distances were required for sensor checks. Behind the maintenance building at the Drone Test Facility is a canyon with a ridgeline 1 km away. The sensor was set up behind the building and aimed at the scoreboard or reflector, which had been placed against the slope 1 km away. The coordinates and elevation of each spot were known from a prior survey; therefore, sensor derived determination of target location and elevation could be evaluated prior to scheduling flight tests.

4.2 HARDWARE DESCRIPTION

At the conclusion of the Phase A flight test program with the "A" model aircraft, a number of required hardware and software changes had been defined. Those changes, labeled "B" modifications, are listed in Appendix C and were incorporated into the 014 and up RPVs. As cited in section 3.5 almost all parts of the Aquila system hardware were affected. Because of the addition of the sensor and sensor electronics assemblies, some RPV hardware had to be relocated or eliminated. The electronics battery was moved aft (from the ballasting position) to its original design position beside the flight control electronics package. The radar beacon was also moved aft to accommodate the sensor hardware. The parachute system was eliminated, because of the high level of Aquila system reliability attained and the weight limitations imposed with a sensor system in the RPVs. The "B" model RPVs required a different series of ballast weights because of the additions, removals, and repositioning of vehicle hardware. Five different sensor models were evaluated during the Phase B flight test program. The Phase I sensor provided real-time video surveillance from an unstabilized TV camera. The Phase II sensor provided an additional 35-mm fixed camera with variable frame rates for subsequent detailed 'image' interpretation. No other sensor model contained a film-type camera. The Phase III sensor provided a stabilized TV camera for target acquisition with a video tracker for continual target tracking.

The Phase IV and V sensors provided the Phase III functions plus a laser range finder. The Phase IV sensor is used for artillery adjustment by first illuminating the target and detecting the laser return. The coordinates and range of the target are then determined. Once a conventional round is fired, the displacement between the impact and target is determined by pinpointing the point of impact with a cursor. The miss distance is displayed in the GCS for artillery adjustment. The Phase V sensor adds a code module for setting the code-of-the-day into the two selectable high laser pulse rates. After determining the position of the target at a low pulse rate as with the Phase IV sensor, a laser-

guided projectile can be launched. The high pulse rates are used for designating the target and guiding the laser-seeking homing projectile, which detects the reflected laser energy.

4.3 TEST APPROACH/PLAN

The Phase B flight test program began on 1 April 1977 with Flight 38 of RPV-013. The first four flights of this series utilized "A" model RPVs, which had been modified with some of the more critical elements of the "B" modifications. The GCS had been modified during the month of March with all of the "B" modifications. The first four RPV flights were for the purpose of evaluating the effects of the more critical changes on RPV and data-link performance. Table 11 lists the objectives of the entire Phase B flight test program. As can be seen, the objectives of the first four flights included evaluation of the new RPV accelerometer, modified RPV dual carburetor, new RPV propeller, relocated RPV command antenna, GCS antenna changes, software changes, standard approach pattern, and dead reckoning changes. A new closed-loop servoed accelerometer had been added because the original model tended to stick with wear and produce undesirable effects during flight. The old blade-type command antenna, which had a poor record of survival during retrieval, was relocated to the original position at the bottom of the propeller duct and changed back to the original type. Evaluation of RPV climb and descent rates and maximum speed, after the engine-related modifications, was an objective. These changes included a new engine mount, dual carburetors mounted on a new induction manifold (in vertical tandem), and a new propeller. Evaluation of the modified ground station antennas and related software, which implemented high/low gain switchover at 5 km, was planned. The original GCS command antenna was used for ranges less than 5 km; the command and telemetry links were multiplexed through the dish antenna (with added parasitic element and preamps) in excess of 5 km.

Open items from the Phase A flight tests included cross-wind recovery demonstration, heading hold and dead reckoning validation, resolution of the roll oscillation problem, and development of a 1- by 2-km approach pattern suitable for use at Fort Sill.

TABLE 11. PHASE B FLIGHT TEST OBJECTIVES AND ACCOMPLISHMENTS

Objective	FLIGHT																											
	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
B Mod Evaluation																												
Engine/dual carb. performance		●	●	●																								
Aero performance	●	●		●											●						●			●				●
Dead reckoning/heading hold	●		●							●				●														
Data link/rf system	●		●																		●							
Roll oscillation										●				●		●												
Software programs/changes	●		●	●											●	●	●	●			●	●	●		●	●	●	●
Support equip (GCS/launch/retrieval)												●									●		●		●			
Approach pattern/abort	●		●	●												●										●		
RPV Check Flight (Sony)					14 ●		15 ●							16 ●	17 ●	16 ●					14 ●		17 ●					
Sensor Performance																												
Phase I																												
Sensor check flight						●		●																●				
Video performance						●		●																				
Sensor performance (det/recog)						●		●																				
Operator training						●		●																●				
Phase II																												
Sensor check flight										●																		
Video performance										●																		
Photo-reconnaissance										●																		
Sensor performance (det/recog)										●																		
Operator training										●																		
Phase III																												
Sensor check flight									●		●																	
Video performance									●			●	●															
Sensor performance (det/recog)									●			●	●															
Operator training									●		●	●	●															
Phase IV (Eye Safe)																												
Sensor check flight																		●								●		
Video performance																		●								●	●	
Sensor performance (target loc/det/recog/acquistn, etc.)																		●								●	●	
Operator training																		●								●	●	
Phase V																												
Sensor check flight																	●					●			●			
Video performance																			●	●		●			●			●
Sensor performance (target det/recog/acquistn/loc/designatn)																			●	●		●			●			●
Laser scoring																				●		●			●			
Operator training																	●		●	●		●			●			●

The remainder of the flight test program was directed toward resolution of problems, check flights of new 014 and up "B" model RPVs, validation of the five sensor types, and training of U.S. Army students. A verification flight was first made with each new RPV with a Sony camera rather than a costly sensor system.

4.3.1 Sensor Systems Flight Demonstration and Validation Program

The sensor flight demonstration and validation program was planned as an integrated Otter and RPV flight test program. This approach afforded the opportunity to check the performance of the sensor and to train both LMSC and U.S. Army operators in a minimum risk environment. The Otter flights became dress rehearsals for the RPV flights and also provided a means for verification of software programs and GCS performance. The approach taken in planning the sensor flights was:

- Plan flights with high commonality of factors to develop operator proficiency and reduce mission planning workload.
- Progress from the least complex to the most complex mission to benefit from operator training.
- Utilize the Otter aircraft to develop proficiency, software, and hardware confidence with minimal risk prior to RPV flight.
- Plan missions to minimize operator-induced results.
- Keep test objectives simple and separate – i.e., detection-recognition separate from location.
- Use post-flight analysis of video and data tapes to produce results rather than real-time data.
- Plan each mission to accomplish all aspects of sensor performance; i.e., all Phase I sensor flights identical and complete.

Figure 28 shows the Otter and RPV flights planned and accomplished during April, May, and June 1977. During these flights, military vehicles were set up as cued road-and-field targets on the east test range. Cued targets, where the type and location were previously known by the sensor operator, were used

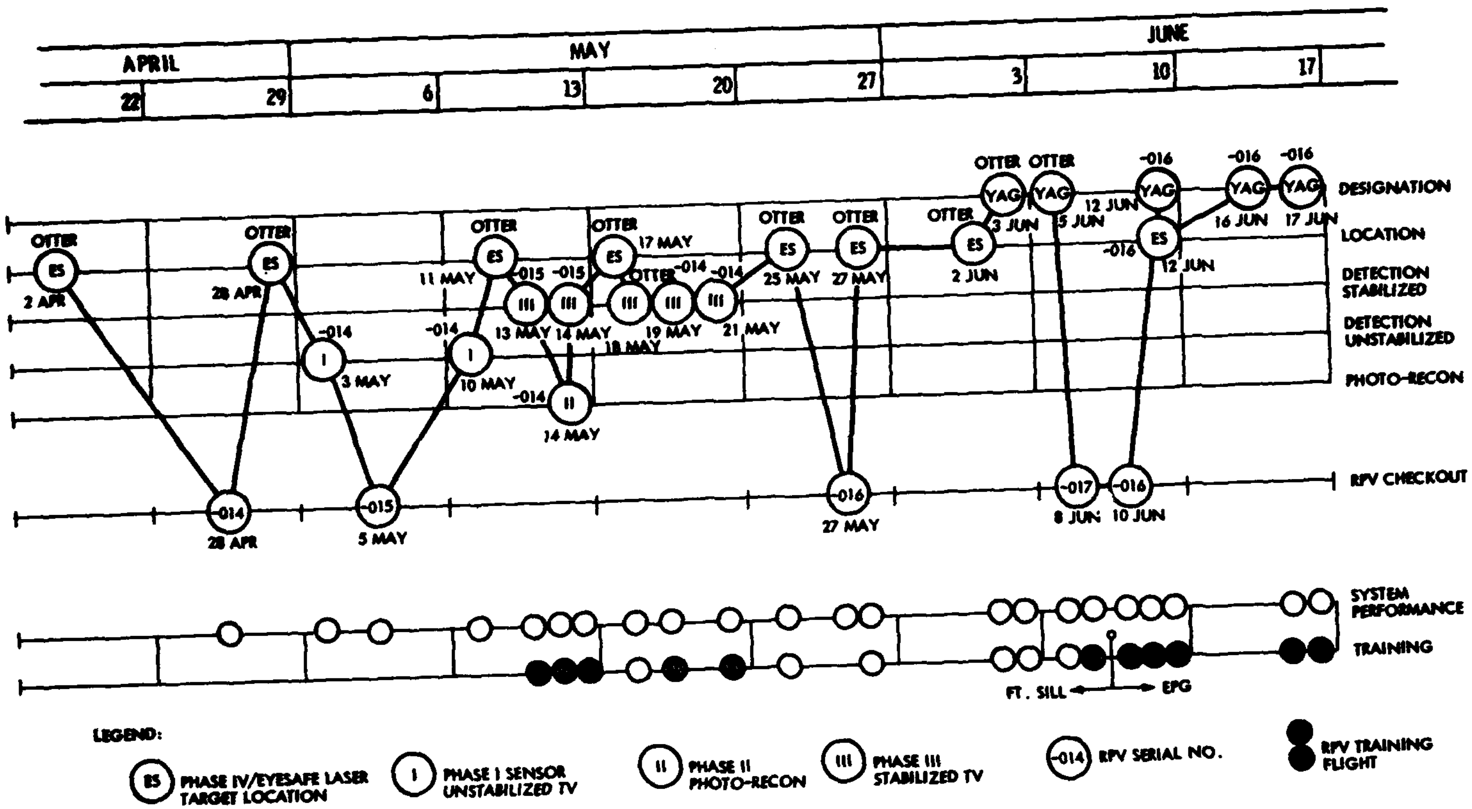


Figure 28. Aquila Series-B Flight Test Accomplishments

to focus attention on evaluation of the equipment and determination of its capability rather than on the combination of man and equipment. It was expected that detection, recognition, and identification ranges would be greater than without cued targets. Three standard flight paths, each with favored target locations, were developed over the east range for the Otter and RPV flights. These flight paths carried the aircraft over or near predetermined target locations or known landmarks, such as the radar spoke and spatial resolution facility. Figure 29 shows the target detection-recognition patterns flown, and the road and field target locations used for evaluating Phases I, III, IV, and V sensors. Figure 30 shows the patterns flown and areas mapped with the Phase II sensor and camera. Figure 31 shows the patterns flown for the laser flights, the target locations lased, and the loiter patterns from which lasing was accomplished.

4.3.2 Sensor System Demonstration and Validation Program Objectives

Objectives of the sensor system flight demonstration and validation test program were:

1. Determine sensor operating limits and capabilities by measuring:
   - Phase I Sensor
     - Detection range against tank-sized targets at road and field locations
     - Recognition range against tank-sized targets at road and field locations
     - System resolution
   - Phase II Camera
     - Basic photographic capabilities
     - Remote control and frame count
     - Post-mission data readout
   - Phase III Sensor
     - Same video sensor performance parameters as Phase I (higher performance values)

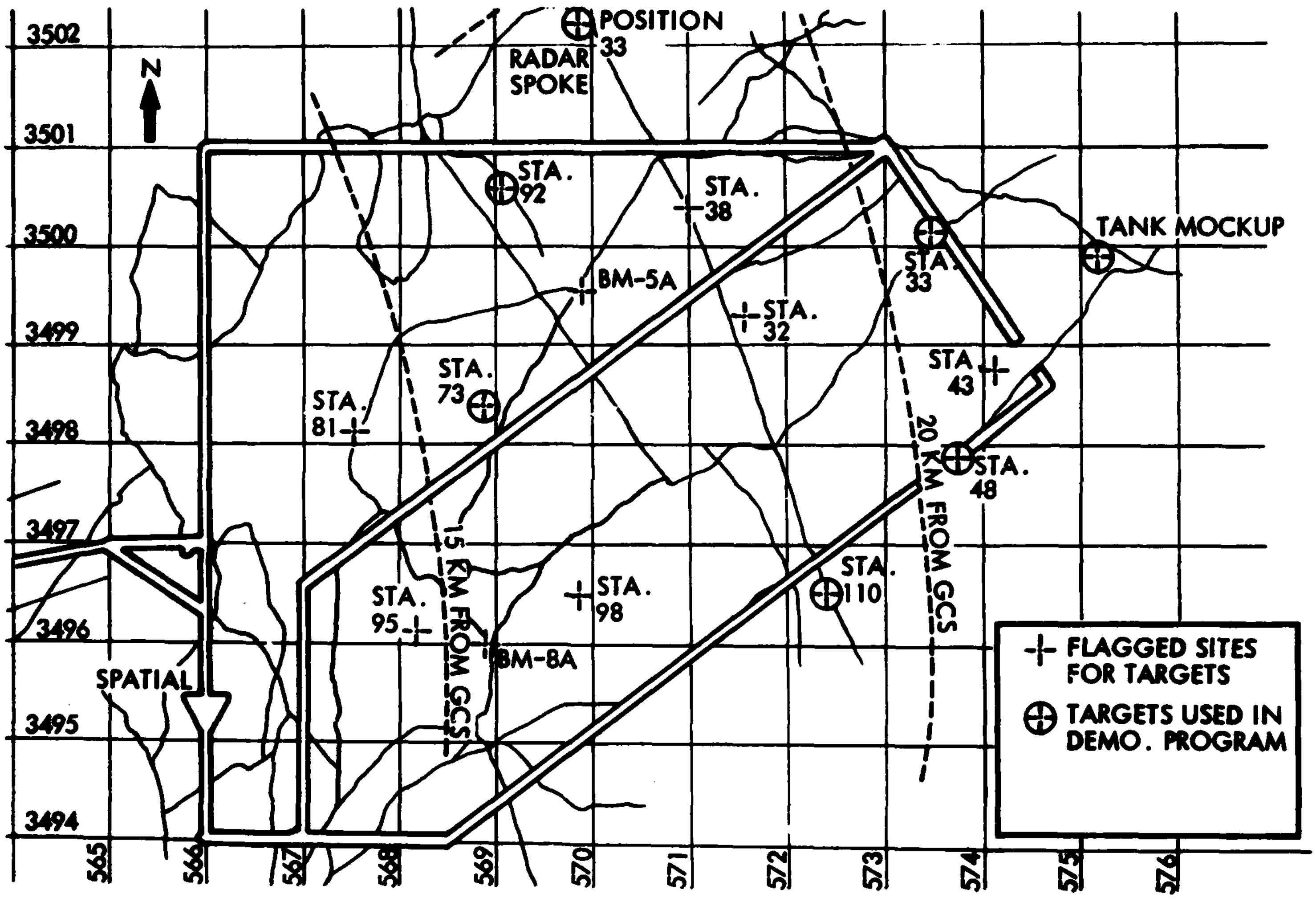


Figure 29. Target Detection/Recognition Flight Patterns

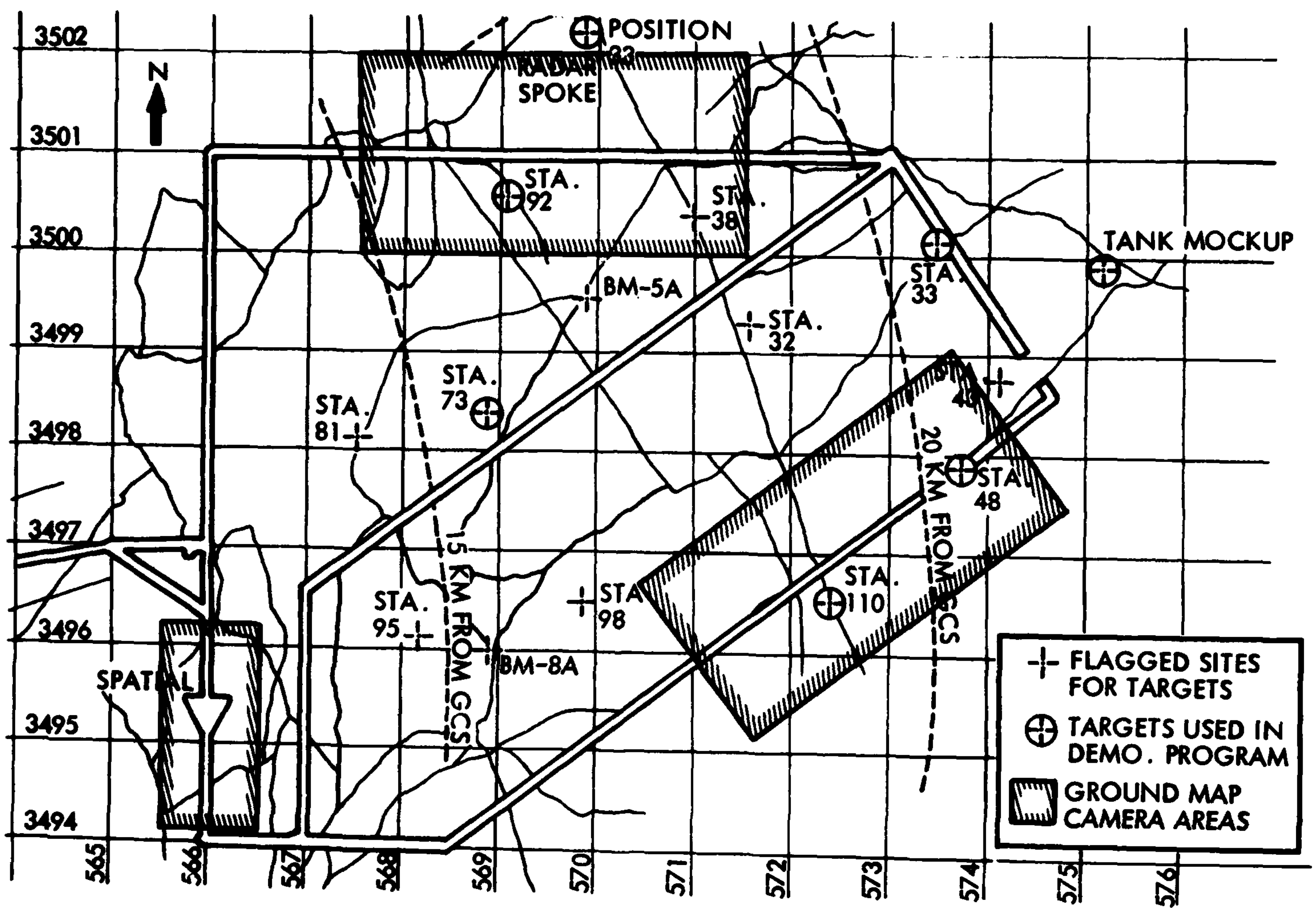


Figure 30. Phase II Camera Flight Test Patterns

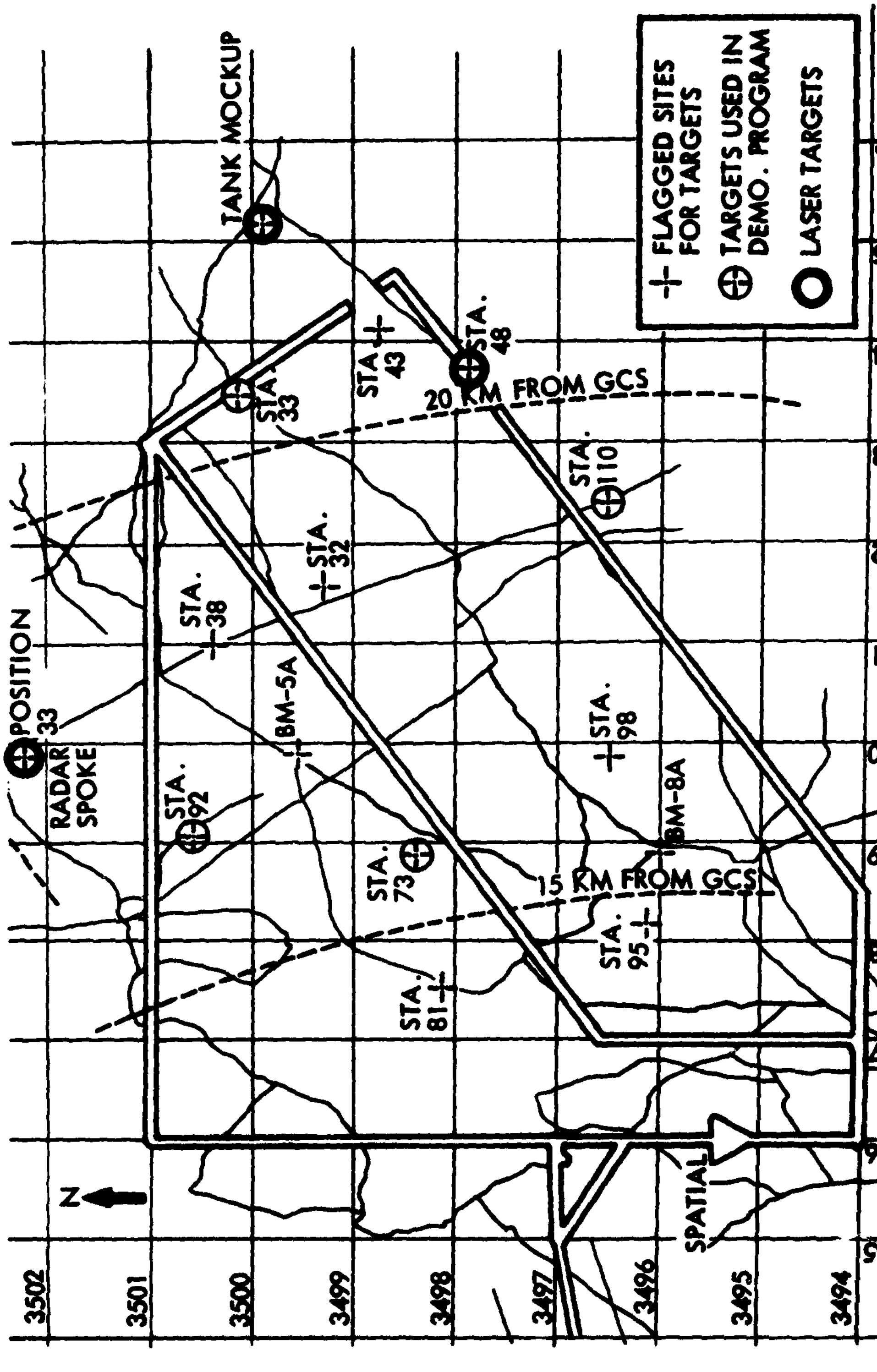


Figure 31. Laser Flight Test Patterns

- Line-of-sight stabilization
- Autotracker performance

- Phase IV-V Sensor
  - Same video sensor performance as Phase III
  - Same stabilization and tracking performance as Phase III
  - Laser target designator performance
  - Laser ranging accuracy
  - Target location accuracy
  - Target elevation accuracy
  - Burst offset accuracy

2. Demonstrate integrated sensor-RPV-GCS system with tactical mission capabilities.
3. Determine performance or design areas needing further refinement.

4.4 RESULTS

Flights 38 through 41 were accomplished during April 1977, with modified "A" model RPVs and "B" model ground control station and launcher. These flights provided data on rate of climb, rate of descent, and maximum airspeed comparisons for the "A" and "B" model engines. These RPVs were configured with a Sony TV camera and parachute assembly. Approximate flight weight was 132 lb. The performance data gathered were used to extrapolate to other altitudes, speeds, and weights by analytical means. Appendix D describes the Aquila RPV flight-performance characteristics derived from data obtained from these four flights, as well as other applicable Phase B flights. Figures 32 through 35 compare engine RPM and rate of climb for the "A" and "B" model engines. Figure 36 shows the launch and retrieval total wind state which prevailed during Flights 38 through 57. Data points were obtained across most of the design criteria envelope. Table 12 is a summary of the Aquila Phase B RPV flight tests. Software changes were being made throughout the test series.

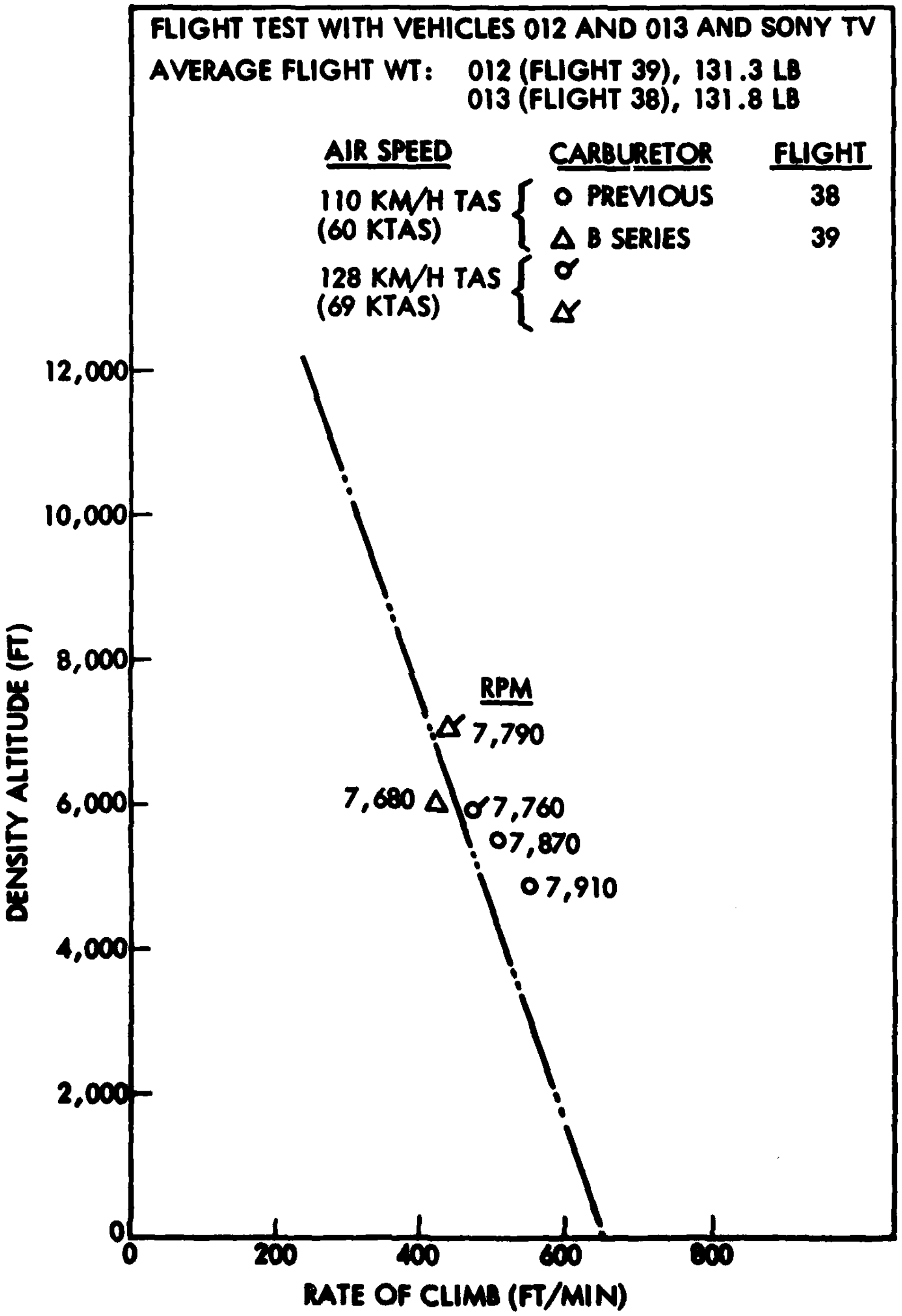


Figure 32. Climb Comparison With Carburetor Change

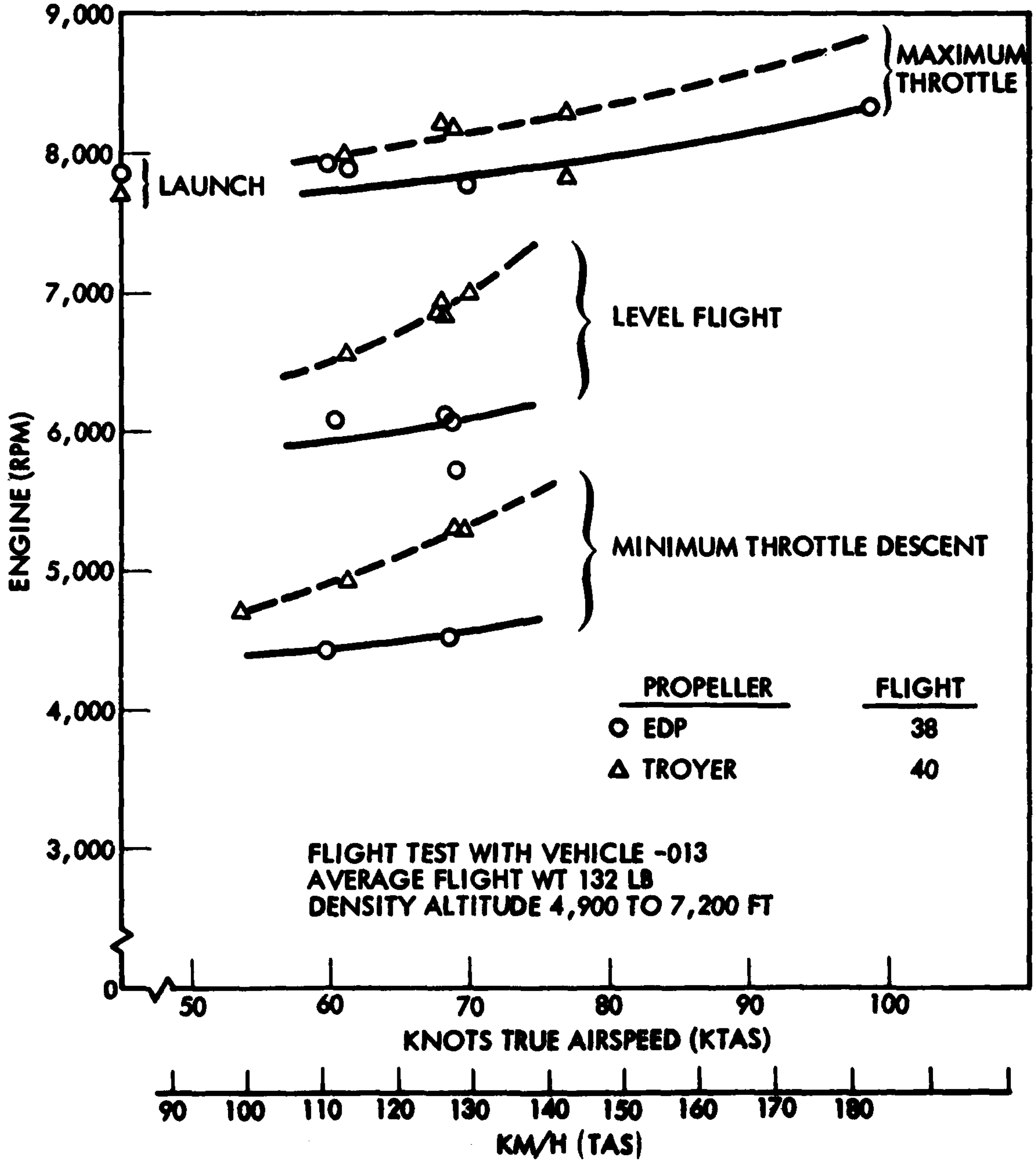


Figure 33. Propeller RPM Comparison

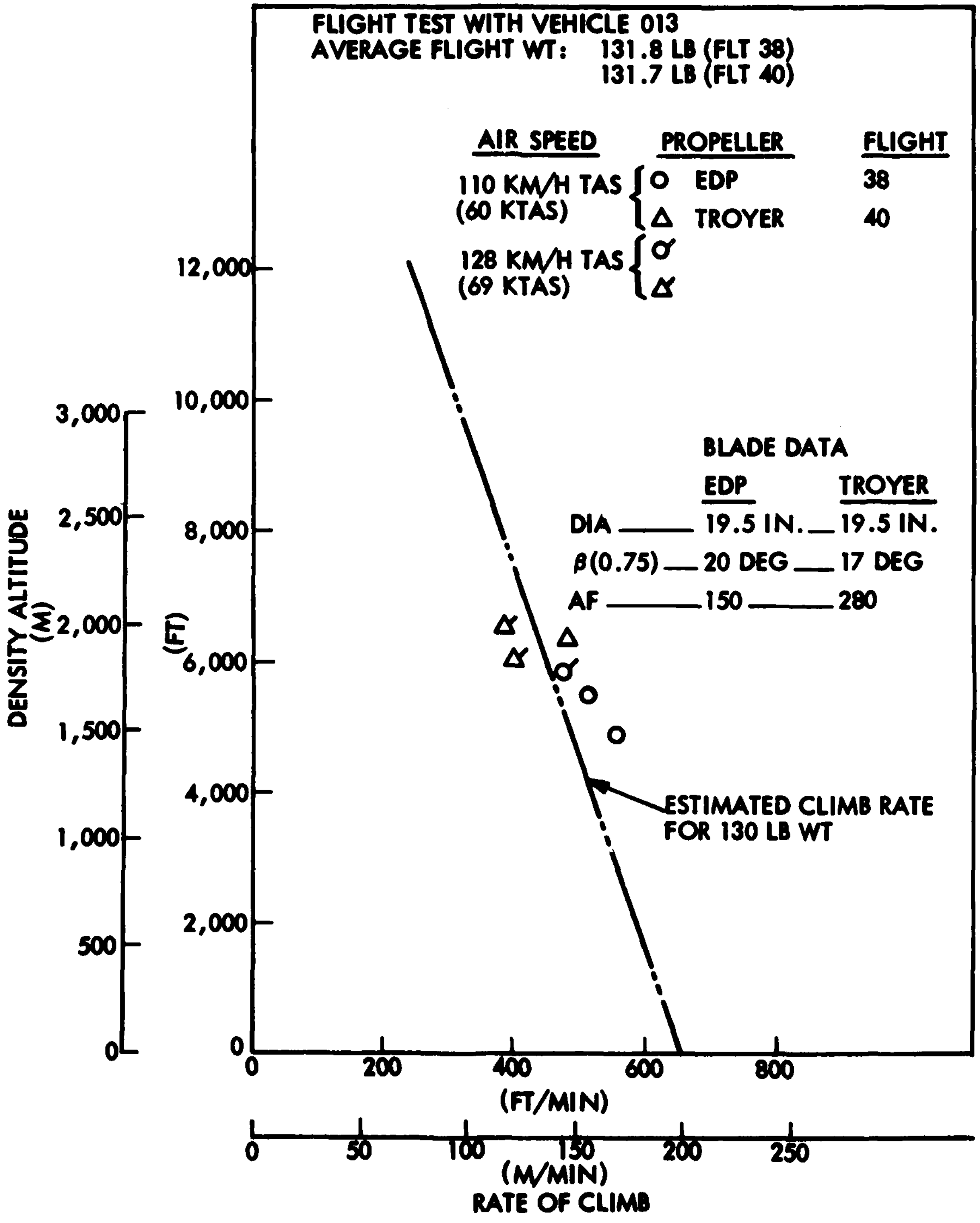


Figure 34. Propeller Climb Performance Comparison

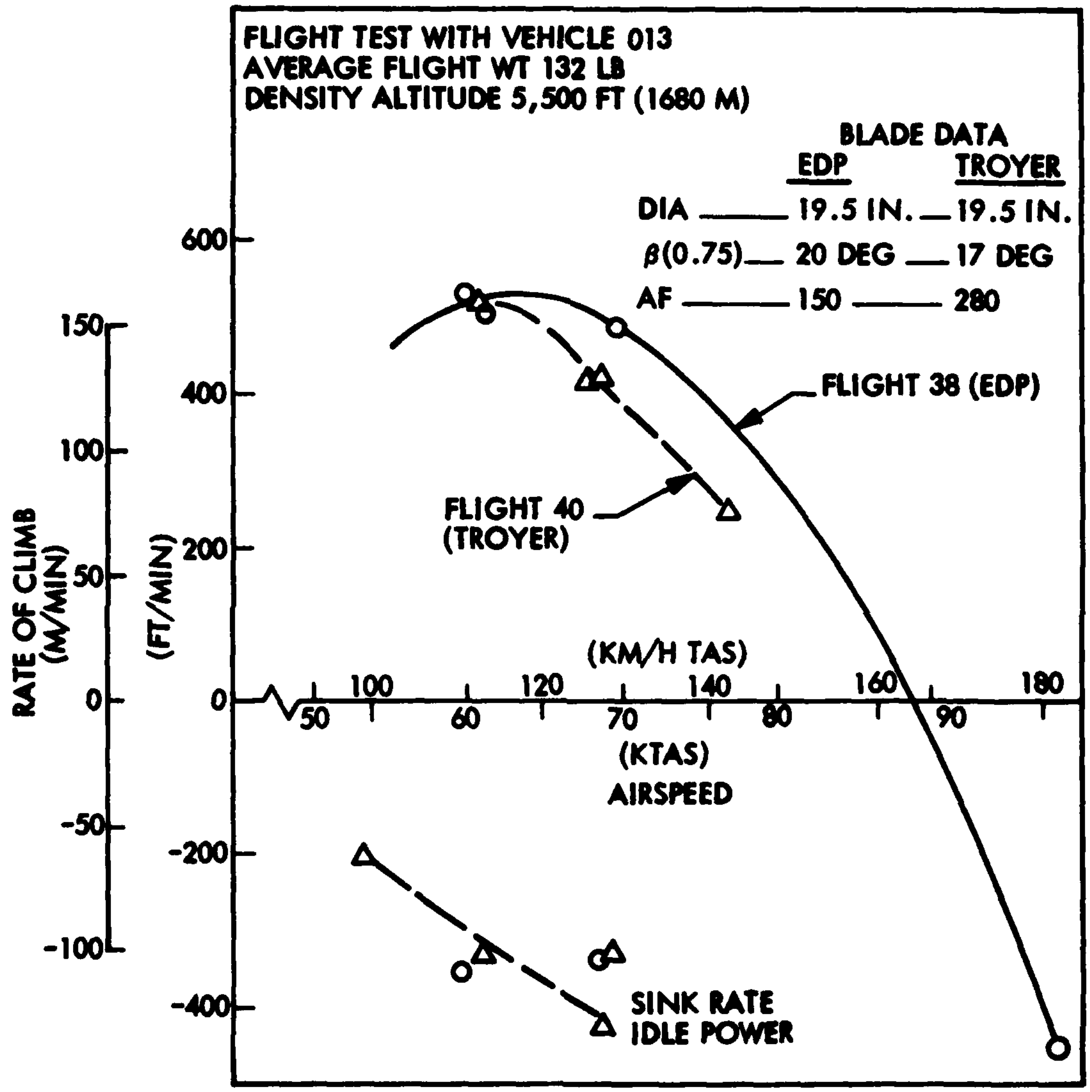


Figure 35. Propeller Climb Rate Comparison

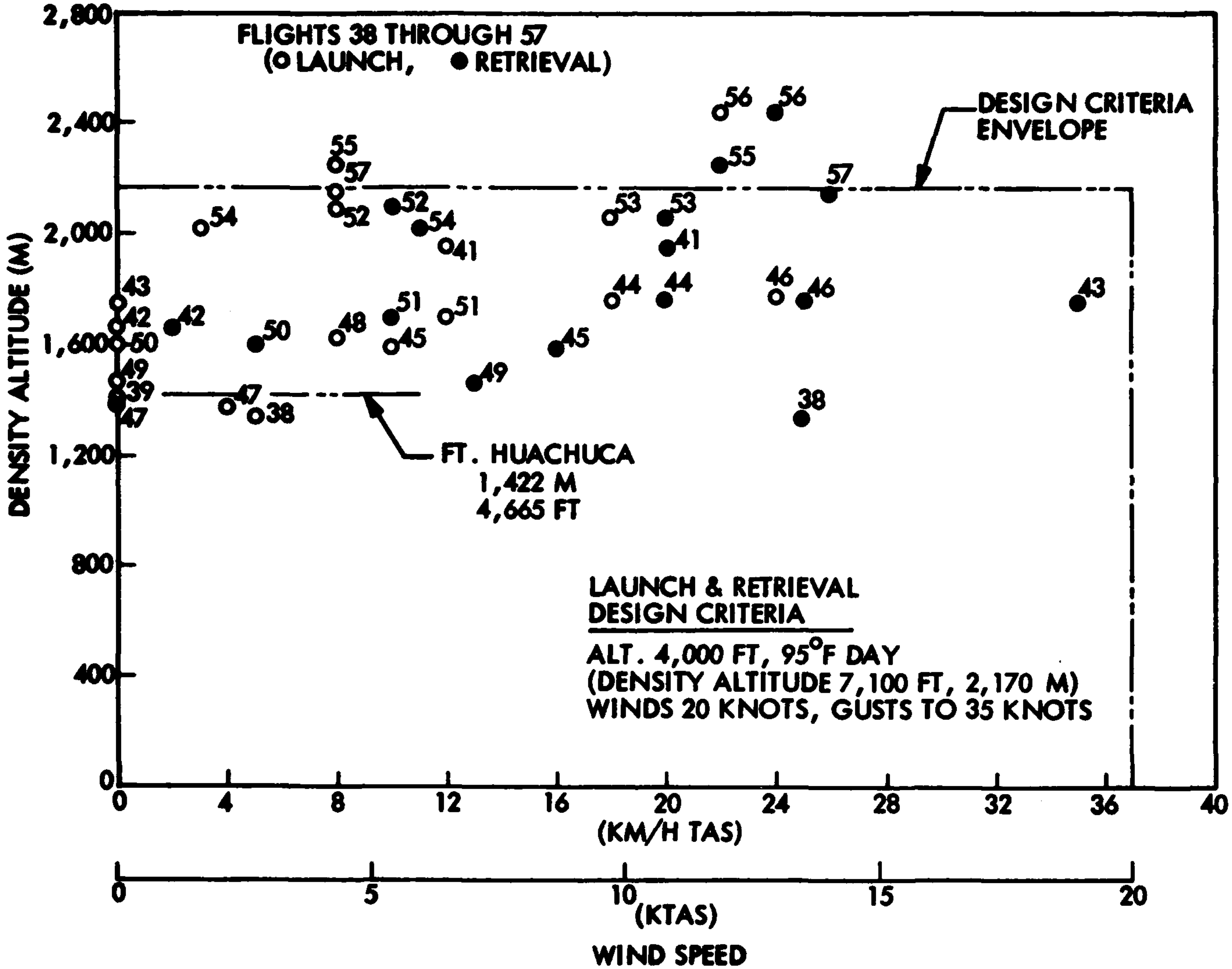


Figure 36. Aquila Launch and Retrieval Total Wind States

TABLE 12. AQUILA PHASE B FLIGHT TEST SUMMARY

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
38	4-1-77	013	66	33	Sony	• Data link performance (video at 3000 ft AGL) at 20 km • Aero-performance • Heading hold check • Standard approach evaluation	RPV: • Good video performance at 3000 ft AGL/20 km RPV: • Heading hold check ok	• Low gain antenna – erratic bearing angle/oscillation • Antenna lost lock • Tracking errors • New rate filter unsatisfactory for 1 × 2 km final approach pattern	None
39	4-8-77	012	60	38	Sony	• Engine performance with new dual carburetor • Aero-performance	RPV: • Good engine performance	• Low gain antenna link losses	Right wing tip
40	4-28-77	013	63	36	Sony	• Aero-performance with new propeller • Dead reckoning check • Data link at 30 km; C^3 and TLM at 1000 ft AGL • Approach pattern evaluation	RPV: • Descent rate of 330 fpm at 5000 rpm • Data link performance very good at 20 km • Dead reckoning check unacceptable • RPV recovered on second pass	• Link dropouts after launch • Link loss between waypoints 00 and 01 • Failure to come out of dead reckoning • Roll oscillations at 10 to 30 km • First approach too high	None
41	4-28-77	012	54	36	Sony	• Engine evaluation with dual carburetor mod • Aero-performance with new prop • Standard approach evaluation	RPV: • Engine performance acceptable • Performance with new prop showed little or no improvement	• Roll oscillations at 10 to 30 km • Approach altitudes too high	• Nose cap • Wing tip
46	4-29-77	014	60	36	Sony	• RPV airworthiness	RPV: • RPV performance data limited due to gusty wind conditions • Standard approach pattern satisfactory	• Phugoid oscillations • Approach waypoints too high • GCS antenna transient due to GCS top-mounted hardware	None

TABLE 12. (Cont.)

Flight Number	Date	RPV	Duration	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
43	5-3-77	014	72	39	ϕI	• Sensor performance (unstabilized) – target detection and recognition	RPV: • 18 knots crosswind recovery • 490 fpm climb rate at 7000 ft altitude Sensor: • No targets detected; road targets improperly located in the field • Excessive image motion at narrow FOV caused by RPV roll/yaw instability and turbulent condition	• Roll oscillations • RPV tracking errors – up to 500 m south	None
44	5-5-77	015	56	39	Sony	• RPV airworthiness	RPV: • 444 fpm climb rate at 7000 ft density altitude • No command or status link losses Sensor: • No sensor data available	• Phugoid pitch oscillations • RPV trkg errors (az.) ~ 100 m at 6 km, RPV 100 m south • Approach altitude too high	• Command antenna sheared off • Left wing tip minor damage
45	5-10-77	014	84	41	ϕI	• Sensor performance (unstabilized) – target detection and recognition	Sensor: • No targets detected; road targets improperly located in field • Excessive image motion at narrow FOV caused by vehicle roll/yaw oscillations and turbulent conditions	• RPV dip after leaving lchr; due to tailwind • RPV trkg errors ≈ 300 m • Roll oscillations • Appch alt too high or too low (RPV recovered on seventh pass)	• Minor nose cap damage
46	5-13-77	015	78	42	ϕIII	• Sensor performance (stabilized) – target detection and recognition • Army training	RPV: • Recovery on first attempt by Army crew Sensor: • No data available due to inability to uncage sensor	• Unable to uncage sensor • Roll oscill. at 0.2 deg/sec $\pm$ (software) • RPV trkg errors – 50 m north • Video loss – overheating	None
47	5-14-77	014	82	42	ϕII	• Sensor performance ~ photo recon • Dead reckoning performance • Roll stability evaluation • Army crew training (Fort Sill)	RPV: • Roll stabil. eval. unsuccessful – software • Good auto search patterns • Dead reckoning unacceptable Sensor: • No targets detected; excess image motion • Camera operations met reqts • Photo exposures reported acceptable	• Dead reckoning – az. timing and reacq. • 1 × 2.5 km appch pattern too tight for trng – alt. too high	None

TABLE 12. (Cont.)

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
48	5-14-77	015	34	42	ϕIII	• Phase III sensor mechanical cage pin fix evaluation • Army training flight (Fort Sill)	RPV: • Mechanical cage pin fix was satisfactory • RPV impacted hill under manual autopilot control while retrieval system being repositioned due to wind shift Sensor: • Sensor functional and optical performance satisfactory	• Approach altitudes too low • Procedural errors • Command altitude errors	Major damage to nose, sensor and bottom of fuselage
49	5-19-77	014	113	42	ϕIII	• Sensor Perf. (stabilized) – target det. and recog. (road and field) • "B" mod launcher performance • Army crew training (Fort Sill)	RPV: • Crew perf. outstanding Sensor: • Sensor perf. acceptable; eval. limited by procedural omissions • Road and field target det. capab. beyond specified ranges	• Tracking errors – heading drift (100 M) and alt. excursions (100 ft) • Sensor LOS off by 15 deg. • Final appch abort (wypt 90 instead of 92) • Engine-kill command did not stop and rewind mag. tape • Minor GCS hardware anomalies – not flight critical • Lchr veloc. meas. equip. malfunction. • Video wavy – recorder caused	One wingtip slightly damaged
50	5-21-77	014	119	42	ϕIII	• Sensor perf. (stabilized) – target det. and recog. • Army crew training (Fort Sill)	RPV: • Total mission accomp. by Army crew • 1 × 3 km appch. pattern appears ideal for student trng Sensor: • Sensor perf. acceptable • Road and field target det. capab. beyond spec. ranges • Target recog. lim. by shadow distortions	• RPV tracking errors 250 m off track • Abort positioning • Engine sputtering due to air bubbles • Engine kill command did not stop and rewind mag. tape • Sensor video wavy • Sensor ALC inoperable • Sensor dome cracked • Indicated airspeed error ≈ +5 km/h	Left wingtip slightly damaged
51	5-27-77	016	87	43	Sony	• RPV airworthiness • DR evaluation • Roll oscillation ($\dot{H}$) evaluation • Army crew training (Fort Sill)	RPV: • Four appch practices – OK w/o alt. chgs • Final appch abort pattern worked well • 480 fpm climb rate at 6000 ft alt • $\dot{H}$ values betw. 0.6 deg/sec and 30 deg/sec appear acceptable Sensor: • No sensor data avail.	• "S" turns due to $\dot{H}$ eval. (0.2 deg/sec value) • RPV – trkg error +40 m northing; +30 m easting • DR az. errors due to software • Engine power reduction appar. due to incr. in carbur. air inlet temp.	Left wingtip, command antenna

TABLE 12. (Cont.)

Flight Number	Date	RPV	Duration (Min.)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
[illegible]	6-6-77	027	[illegible]	40	Sony	• RPV airworthiness • Software version 40 checkout • Army crew training (Ft. Sill)	RPV: • Excellent army crew perform. • RPV performance acceptable climb rate ≈ 400 fpm at 8000 ft altitude (limited data) • Dead reckoning check not performed Sensor: • No sensor data available	• Antenna switching/side lobe tracking • Ground lock light intermittent/low signal strength • Alternator low light • Secondary approach altitudes too low	Left wing up
[illegible]	6-10-77	030	32	51	Sony	• Software version 51 checkout	RPV: • Automated final approach pattern worked well • Roll stability much improved Sensor: • No sensor data available	• GCS altimeter errors • Short duration side lobe tracking shortly after launch • RPV tracking error 150-200 m South	None
54	6-12-77	026	37	51	ϕV	• Phase V sensor performance • Software version 51 checkout • Army crew training	RPV: • Successful retrieval on first attempt Sensor: • Sensor performance data unavailable due to failure to uncage	• Video sync problems • Mechanical uncage unsuccessful • Status link intermittent • Sensor dome cracked	None
[illegible]	6-12-77	016	[illegible]	51	Eye Safe	• Eye-safe sensor performance – target location • Software version 51 checkout • Army crew training (USAFGS)	RPV: • Successful retrieval on first attempt Sensor: • Sensor performance data unavailable due to failure to uncage	• Mechanical uncage unsuccessful • RPV antenna tracking errors ≈ 200 m South	Sensor dome cut due to sensor movement at launch

TABLE 12. (Cont.)

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
56	6-16-77	016	57	51	ϕV	• Sensor performance – target designation • Army crew training (USAEPG)	RPV: • Successful first attempt recovery by Army crew Sensor: • First RPV lasing • Target locations within 100 m	• Back lobe tracking at launch • Low airspeed during first loiter • Video malfunction	• None due to recovery • Dome crack (1/2 in. vert/rear – repairable)
57	6-17-77	016	118	51	ϕV	• Sensor performance – target designation • Army crew training (USAEPG)	RPV: • Successful first attempt recovery by Army crew Sensor: • Burst offset – 54.6 m vs 51 m measured • 90 percent of observed hits within 2 m circle • Target locations within 140 m	• Minor – video out of focus • Sensor battery deterioration • Azimuth slew mechanically limited due to sensor gimbal binding	• None
58	6-20-77	014	61	53	Sony	• West range (20 km) ops • Max altitude • Ck software and antenna mode • Evaluate lo-gain antenna ops • Army crew training (USAEPG)	RPV: • Max altitude of 3,658 m • Max range (west) 20.5 km • Successful crew performance Sensor: • No sensor data available	• "S" turns • Data link degraded • Link loss during lo-gain antenna test	• None

TABLE 12. (Cont.)

Flight Number	Date	RPV	Duration (min)	Software Version	Sensor	Flight Objectives	Performance	Anomalies	Damage
59	7-1-77	016	54	53	ϕV	• Software Ck • Laser "jitter"/cycling/scoring • Sensor uncage, TVL resolution, dome fix evaluation, stab. sensor detect at 20 deg FOV, overheating • Army crew training (USAEPG)	RPV: • Successful recovery on second attempt by Army crew Sensor: • Performance data not available due to failure to uncage sensor	• Sensor uncaging • First pass too high • "S" turns	• Both wing tips • Nose cap
60	7-6-77	017	81	53	Sony	• Software ck • GCS antenna ck • Army crew training (USAEPG)	RPV: • Successful crew training Sensor: • No sensor data available	• Alt. low light • Video break-up • Excursions from programmed altitude • Return from loiter • P/L protect. deploy.	• Cracked wing tip • Sensor damaged
61	7-7-77	014	180	53	ϕI	• Sensor Performance • Max speed • Endurance • Army crew training (USAEPG)	RPV: • Max airspeed of 160 kmph • Endurance of 3 hours Sensor: • Some improvement in unstab. sensor performance	• Alt. low light flicker • Sensor "blooming" • RPV "porpoising"	• None
62	7-7-77	016	137	53	ϕV	• Sensor performance-target designation/laser scoring • Sensor Uncaging • Software ck-target location • GCS antenna ck • Army crew training (USAEPG)	RPV: • Successful crew training Sensor: • Improved laser target info and scoring data • Sensor uncaged	• Sensor "fogging" • Sensor "jitter"	• Wing shoulder crack
63	7-8-77	017	86	53	Eye Safe	• Search pattern evaluation • Sensor uncaging • ϕV sensor performance • Final approach abort check • Army crew training (USAEPG)	RPV: • Normal launch • Successful recovery Sensor: • Good search pattern performance	• Total azimuth control not available for sensor • Dome moisture	• None
64	7-9-77	017	79	55	Eye Safe	• Artillery battery loiter • Software verification • Army crew training (USAEPG)	RPV: • Initial climb rate 200–300 fpm • 3 loiter evaluations Sensor: • Data limited due to inoperative tracker	• Inoperative sensor tracker	• None
65	7-10-77	014	181	56	ϕV	• Sensor performance • Software verification • Endurance • Army crew training (USAEPG)	RPV: • Total success w/several practice approaches Sensor: • Laser targeting/burst offset data "quick look" – very good • Gun line loitering successful	• Dome moisture – dissipated later	• None

Phase B flight tests and Army certification were originally scheduled for completion on 17 June 1977 (Flight 57) because of limitations on existing funds. During an Army review of the Aquila RPV-STD system validation and test program at the contractor's Sunnyvale plant on 22 to 24 June 1977, it became apparent that several objectives had not been satisfactorily completed. The Army directed LMSC to continue the flight test program for two additional weeks to provide more validation in sensor operation and to complete certification of the USAEPG crew. TRADOC personnel had been certified on 5 June 1977. Eight additional training and data flights were accomplished by the USAEPG crew. Two of the flights (58 and 60) were software and antenna modification check flights with a Sony TV in the RPV. Flight 61 was a three hour endurance and maximum airspeed (160 KPH) flight with the unstabilized Phase I sensor. The remaining flights utilized the eye safe or Phase V YAG laser and were sensor validation flights. Flight 65 with the Phase V sensor yielded the greatest amount of usable validation of any sensor flight to date. This series of flights also demonstrated that a solution to the sensor uncaging problem had been accomplished.

4.4.1 Flight 38

Flight 38 validated the data-link performance at a 2,000-ft AGL altitude and 20-km range. The heading hold check of the software and flight control electronics package was also successful. The heading rate filter time constants used in Version 33 of the software for the 1- by 2-km approach pattern produced too much overshoot and was unsatisfactory. There were loss of lock problems between 3 and 5 km range in the low-gain antenna mode, indicating an area of reduced coverage with the low-gain antenna. In a subsequent software version, the switchover to high gain was reduced from 5 to 4 km, which vastly improved the situation. (Table 13 indicates TM data dropouts during Flights 38 through 57.) RPV tracking accuracy over the east range (14 to 20 km range) was in error in a north-south direction by 100 m. Flight 38 was used as a baseline data flight for comparison of engine-related B modifications.

TABLE 13. DATA-LINK PERFORMANCE

Flight	Duration (sec)	Telemetry Dropouts (sec)	Command Dropouts (sec)	Number of Transitions Low to High	Number of Transitions High to Low	Remarks
38	3,960	128	125	4	3	Dropouts caused by low gain antenna slewing
39	4,140	131	100	2	1	Dropouts caused by low gain antenna slewing
40	3,780	30	15	4	3	Dropouts caused by low gain antenna slewing
41	3,240	0	0	7	6	
42	3,600	0	0	22	21	
43	4,320	0	0	3	2	
44	3,360	0	0	6	5	
45	5,040	0	0	10	9	
46	4,680	0.2	0	2	1	
47	5,520	11	11	2	1	Dropouts caused by flying RPV over GCS during DR (high-gain mode)
48	2,160	0	0	2	1	
49	6,780	0	0	3	2	
50	7,140	0	0	3	2	

TABLE 13. (Cont.)

Flight	Duration (sec)	Telemetry Dropouts (sec)	Command Dropouts (sec)	Number of Transitions Low to High	Number of Transitions High to Low	Remarks
51	5,220	10	10	5	4	Dropouts caused by flying RPV over GCS during DR (high-gain mode)
52	1,560	20	14	5	4	Dropouts caused by shift in antenna servo error bias
53	4,920	1	0.4	2	1	
54	2,220	49	1	5	4	Dropouts caused by low RPV transmitter power
55	3,960	0	0	1	0	
56	3,420	4	3	3	2	Dropouts caused by launching in back lobe
57	7,080	0	0	1	0	

4.4.2 Flight 39

Rates of climb and descent, as well as maximum speed, after relocation of the dual carburetors to the new upper induction manifold were obtained. Figure 33 compares the rate of climb of Flight 39 with that of Flight 38. If anything, a slight loss in climb rate was realized. Since the primary reason for making the change had been to provide a more reliable and consistent way of adjusting the carburetion, the loss which was based on a sample size of one was not considered to be a serious factor. The Aquila performance characteristics described in Appendix D utilized the data obtained in this flight.

4.4.3 Flight 40

The new Troyer propeller was added to RPV-013 for this test. A comparison with Flight 38 was then obtained (Figure 33 through 35) with the same RPV over the same flight path. A slight degradation in climb performance was realized, and the Troyer propeller was later abandoned as a candidate. The RPV failed to exit the dead reckoning mode or to fly the legs properly. Data analysis revealed circuit anomalies and formulation errors with the design concept. Required design changes were defined but not authorized by the Army for corrective action. Reference Volume II, Section 3.4.4.2, Guidance Mode Evolution-Dead Reckoning.

4.4.4 Flight 41

Flight 41 included both the Troyer propeller and the relocated dual carburetors. Again the Troyer propeller indicated no improvement. Roll oscillations were still noted over the east range beyond 10 km. (Refer to Volume II, Section 3.4.4.2, Waypoints, for discussion of this problem.) Engine performance was satisfactory.

4.4.5 Flight 42

This was a check flight of the first "B" model aircraft (RPV-014). The RPV performed very well, and a compromise standard approach pattern was successfully evaluated.

4.4.6 Sensor Evaluation Flights

These flights, summarized in Table 12, were generally sensor performance evaluation and Army training flights; however, included within this series were six RPV check flights with Sony television cameras. Those flights were 44, 51, 52, 53, 58, and 60. The purpose of Flight 44 was to verify the airworthiness of "B" model RPV-015 on its maiden flight. The flight was confined to the west range with a maximum distance from the GCS of 6 km. Climb rate of the air vehicle was checked and the maximum obtained was 444 fpm at a density altitude of 7000 feet. Winds of 18 to 25 km/h from the south (Huachuca Mountains) existed throughout the flight. Air turbulence from the mountains caused the RPV to undergo several pitch-type phugoid motions with a period of 10 to 12 sec. Three cycles were required for damping and the altitude rate varied +100 to -100 m/min.

Flight 51 was the maiden check flight of "B" model RPV-016 and was used to evaluate several software changes. Validation of the software change to the final approach abort pattern was accomplished. Instead of the RPV continuing around the landing pattern on issuance of the abort command, the RPV was directed to turn toward WP 80/90 to shorten the go around time. The software was also changed to restrict erection of the vertical gyro to roll and pitch angles less than ±4 deg. This was later changed to ±6 deg because of excess gyro drift. Calculation errors of target location had been occurring, because the vertical gyro was being falsely erected during turns. This software change improved the target location CEP.

Another flight objective was to evaluate the neading command limit software change to suppress roll-yaw oscillations. Rate limits of 0.2 and 0.6 deg/sec were evaluated. The 0.6 deg/sec heading rate limit produced the best flight-path control; however, some snaking along the programmed waypoint line at ranges beyond 12 km was noted. (This problem was ultimately solved and demonstrated at White Sands after the conclusion of the RPV-STD basic program by inserting aircraft magnetometer data into the control loop via a software change.) The original 30-deg/sec limited was selected during the flight for comparison with the new candidate limits. Short periods of 0.5-Hz oscillation with sharp peak roll-yaw gyro rates of 30 deg/sec were observed. Transfer to 0.2 deg/sec repeatedly caused the RPV waypoint guidance loop to break into oscillation with a rate of about 1 cycle/min. Transfer to the 0.6-deg/sec limit resulted in an occasional 0.25-Hz oscillation with peak roll-yaw gyro rates of up to 10 deg/sec. The RPV video display confirmed a well-behaved attitude control loop without severe roll or yaw perturbations.

Flight 52 was the maiden check flight of RPV-017. Flight performance Army crew training and software change verification were the flight objectives. During the flight, considerable difficulty was experienced with the GCS antenna switching from high to low gain and locking on a side lobe. Postflight data analysis revealed that the RPV had been programmed to fly at a marginally high elevation angle of 10.5 deg. The RPV consistently flew 40 m north of the intended flight track. Postflight analysis indicated a drift in the GCS antenna servo error bias from null to +0.8 V had occurred. RPV flight performance was otherwise acceptable.

Flight 53 with RPV-016 was a software check and Army crew training flight. Software changes to the final approach landing pattern and roll-yaw stabilization were verified. The RPV was again reported by the radar tracking facility to be flying 150 m south of the intended path over the east range (range greater than 12 km). Postflight analysis revealed that the GCS appeared to have a -0.46-deg antenna beam-pointing error. This was thought to have been caused by an improper site survey; however, resurveys of the area produced inconsistent results. A software change was ultimately made to eliminate the bias error.

Flight 58 was a USAEPG training flight with RPV-014 to maximum range and altitude. Verification of GCS antenna control unit modifications (refer to Volume II, section 4.6.1, Tracking Antenna for details) was also a prime objective. These fixes helped to some extent but high-gain/low-gain switching continued to be a nuisance at high elevation angles. (The contractor later designed a dual axis antenna which could also track in elevation. This unit was ultimately tested at White Sands and Fort Huachuca on GCS-002.) Maximum altitude achieved during Flight 58 was 3,658 m MSL (12,000 ft) and the maximum range was 20.5 km.

Flight 60 was a GCS antenna performance and USAEPG crew training flight with "B" model RPV-017. Status link dropouts and degradation were found to coincide when the RPV was behind the weather vane mast or lightning rod (attached to the roof of the GCS). RF multipath from the test support vans caused tracking anomalies, when the RPV was in line and behind the vans. The usual form of this anomaly was side-lobe tracking. The azimuth angle of the anomaly agreed with data obtained during the Otter flight of 28 March 1977. The payload protector failed to deploy even though commanded, apparently due to a jammed cable. All post-flight checks were normal.

During the sensor evaluation phase, several problems were encountered. Some of these required hardware modification and followup validation flights. These problems are described in section 4.5 of this volume and in Volume II, section 3.5.4, Sensor Evolution.

4.4.7 Phase I Sensor Flights

During Flights 43, 45, and 61, performance of the Phase I sensor was evaluated. No targets were detected during Flights 43 and 45 because of aircraft-caused image motion at the narrow field of view. Buffeting of the aircraft by thermal up and down drafts plus the roll/yaw oscillation problem greatly reduced the effectiveness of the Phase I sensor. Also, as mentioned above, the sensor test program used only cued targets. Flight plans generally included the cueing

data for observing each target in sequence as they occurred during the flight. Unfortunately, during the early days of the sensor test program, the targets were often set in the wrong location and the sensor operator spent effort and time searching for these offset targets. Not until later in the program (Flight 61) was it possible to collect any reliable Phase I data. Flight 61 also included a maximum airspeed and endurance run (not simultaneously); 160 km/h and 3 hr were achieved. Sensor performance is discussed in later sections of this volume.

4.4.8 Phase II Sensor Flight

Flight 47 was the only RPV flight with the Phase II photo-reconnaissance camera. No targets were detected with the unstabilized video system; however, camera operation and photo exposures were satisfactory.

4.4.9 Phase III Sensor Flights

Four RPV flights were accomplished with the stabilized Phase III sensor. Those flights were 46, 48, 49, and 50. No sensor data were obtained during Flight 46 because the sensor could not be driven out of the mechanical cage. During that flight the vidicon became overheated and all video ceased. The source of heat was attributed to the mechanical cage drive motor; the drive pin became jammed as a result of the launch forces on the gimbal.

Flight 48 evaluated the Honeywell fix to the mechanical cage pin. The sensor performed well during a short check flight over the west range. During the flight, the wind direction changed and it became necessary to re-rig the retrieval nets for the opposite approach direction. While this was being accomplished, the RPV was flown in the manual autopilot mode toward the south-east hills. Unfortunately, neither video monitor in the GCS was displaying RPV video at that time. The sensor operator had selected ground video to direct ground camera alignment, and the student pilot's TV monitor had been turned off as a part of his training. Terrain clearance was not anticipated adequately

and the RPV was flown into a hill. No hardware or software malfunction had occurred, and the loss of the RPV was due to operational errors within the ground control station.

Flights 49 and 50 evaluated performance of the Phase III stabilized sensor. Road and field targets were set out on the east range at ranges between 12 and 21 km from the GCS. All targets were detected at least once, and many targets detected several times on repeated circuits of the east range. Results of the sensor evaluation program are discussed in section 4.6, Summary and Conclusions. RPV performance was good; however, phugoid-type altitude excursions of 100 ft were noted. These were the first flights launched from the "B" model launcher, which contained the new shuttle, dryer, quick-disconnect umbilical, and cooling duct. Launcher performance was flawless, except for malfunction of the velocity measuring equipment. Aside from that problem, performance of the B model launcher was validated.

4.4.10 Phase IV Sensor Flights

Flights 55, 63, and 64 utilized the Phase IV or V Eye-Safe laser. During Flight 55, RPV and GCS performance was satisfactory; however, sensor performance data were not obtained, because the sensor gimbals could not be driven out of the mechanical cage. Also, the upper rear part of the sensor dome was cut during launch when the gimbal shifted aft. (Refer to the discussions on camera-dome mechanical interference in section 4.5.3 and mechanical age problems in section 4.5.7.)

Flights 63 and 64 were primarily software and sensor checkout flights; target detection, recognition,and designation were not objectives. Sensor performance was satisfactory except for two spots of azimuth slew binding and some fogging within the dome during Flight 63. The binding problem was caused by an interference between the top collar of the dome and the ground check alignment mirror on the gimbal. A more thorough preflight check of the sensor eliminated

this flight problem on subsequent Army flights. The fogging problem was subsequently minimized by nitrogen purging and the addition of desiccant material within the dome. The square-wave search pattern and final approach abort maneuver were satisfactorily accomplished during Flight 63, thereby validating those software programs. During Flight 64 the artillery battery loiter program was satisfactorily accomplished, thereby validating that software program.

Sensor autotracking of targets was unsuccessful, because the tracker had become inoperative after launch. However, lasing operations were performed in the manual track mode.

4.4.11 Phase V, YAG Laser Flights

Flights 54, 56, 57, 59, 62, and 65 were all scheduled as target designation flights. No sensor performance data were gathered during Flight 54 because the gimbals could not be driven out of the mechanical cage (the mechanical cage pin jammed during launch). Sensor video was poor because of vertical sync problems; the status link remained solid at that time. The mission was aborted shortly after reaching the east range when the status link appeared to deteriorate. RPV aerodynamic performance and GCS controls were satisfactory throughout the flight.

Flight 56 was the first YAG laser firing flight from an RPV. Two orbits of the artillery battery offset loiter pattern were accomplished near station 48 over the east range. The target vehicle was lased on at a 1 pulse per second (pps) rate while in the autotrack mode at a slant range of approximately 1.8 km. Target location readouts in the GCS were within 100 m of the known target location. Approximately 18 min after payload power had been commanded (25 min into the flight), the video disappeared, because of overheating of the vidicon. This problem was caused by the caging problem discussed in section 4.5.7. Video remained off throughout the rest of the flight. The RPV was flown back to the retrieval area in the automatic mode and successfully recovered without RPV video.

Flight 57 was the first laser scoring flight using an RPV. A large white target board (approximately 8 ft square) was set next to a 2-1/2-ton Army truck at the Radar Spoke Facility on the east range. A television camera with special filter and video recorder were used at the target site for recording the laser hits. The RPV was flown in a loiter pattern approximately 1 km distance and at an altitude of 600 m AGL. Approximately 90 percent of the hits were within a 2-m circle on the target board and approximately 30 percent were within a 1-m circle during a 20 sec laser burst. The laser was fired at a 10-pps rate while in the autotrack mode. Burst offset data were gathered on a target vehicle, which had been parked 51 m from the target board. The first burst offset test yielded values of 42 m west and 35 m south, or 54.6 m distance. Altitude readouts averaged about 80 m low. The artillery batter loiter offset pattern was automatically entered 1,800 m before the target, after having first lased it from a range of 3,500 m. Target location coordinates presented in the GCS were within 140 m of the known location.

Flight 59 was planned as a laser designation scoring flight; however, after launch, the sensor would not come out of the mechanical cage. The flight mission was aborted after two turns around the east range and without firing the laser. RPV, launcher, and GCS performances were without incident. The roll oscillation problem was still evident, because Range Operations personnel reported the RPV to be snaking and south of the intended track along the east-west legs over the east range.

Flight 62 was scheduled to obtain the data not gathered during Flight 59. The sensor did come out of the mechanical cage and functioned well during the flight. The laser was fired at 1, 10, and 20 pps during the flight for several burst intervals of up to 20 sec. The accuracy of target location information was improved over some of the prior flights, although the targeting errors were still excessive compared to the specified requirements. It was subsequently realized that the magnetometer may have been giving erroneous data which could have caused the large errors. Sensor performance data are described in a later section of this volume. The RPV flew well, and all vehicle system components functioned normally.

Flight 65 was the last flight of the Phase B flight test series prior to DD-250 of the Aquila system hardware. Although a Phase V sensor was flown, no laser scoring was attempted. The flight was 3 hr in duration (a new record) over the east range. Laser targeting data were obtained and are referenced in Appendix E. Burst offset was also attempted but failed to yield any meaningful data. The artillery battery (gun line) loiter pattern was successfully flown. Some moisture within the dome was evident above 2,000 m MSL, indicating that nitrogen purging is required to ensure the ability to fire the laser and interpret the video without degradation in performance.

4.4.12 Phase I Sensor Test Results

Referring to Table 14, it can be seen that dynamic resolution measurements with each sensor type fall short of the specifications. In the case of the Phase I sensor, an excessive amount of motion was continually present because of air-frame motion coupling directly to the sensor. Cause of the motion was air turbulence and the roll-yaw oscillation problem.

Other factors that can have an effect on resolution are:

- The measurements were nominally made at a 30-deg look angle. With this geometry, the spatial resolution target was fairly large and almost filled the screen. This means that the smaller resolution elements were usually observed at one edge of the screen. The measurement therefore represented edge resolution rather than center resolution. The camera resolution varied from 450 TVL/ph (TV lines per picture height) in the center to 350 TVL/ph at the edge. Thus, the edge resolution of the system will not be as good as in the center.
- The measurements were made from tapes of the original video. Some degradation due to video data processing can be expected.
- No tracking was used during this measurement, although in Phases III, IV, and V the sensor was stabilized. This means that the TV image was moving continuously and was, therefore, difficult to interpret. Stop frame techniques were attempted on the tape recorder to overcome this; however, this again caused image degradation.

TABLE 14. SENSOR TEST PROGRAM RESULTS

Parameter	Phase I (Flight 61)		Phase II (Flight 47)		Phase III		Phase IV – V	
	Spec.	Results	Spec.	Results	Spec	Results	Spec.	Results
Dynamic Resolution TV Lines/Picture Height (Measured with Vertical Lines)	300	180 (single measurement)	TV resolution as in Phase I Panoramic 40 lp/mm (goal)	TV resolution as in Phase I Photo camera 24 lp/mm	300	Low = 180 High = 250 4 readings – Flights 40, 50, 65	See Phase III results, identical camera therefore results combined with Phase III	
Target Detection Slant Range (m) Road	3,000[a]	Low = 1,075 High = 2,161 (FOV = 20 deg)[b]	See Phase I results		5,000	Low = 1,297; Mean = 4,845; High = 8,014 (FOV 12 deg); σ = 2,506	17 measurements of combined Phases III, IV, V flights 40, 50, 65[b]	
Target Detection Slant Range (m) Field	1,500	Low = 846 (FOV = 12 deg)[b] High = 1,125	See Phase I results		2,500	Low = 1,526; Mean = 2,282 High = 3,371; σ = 762	11 measurements of combined Phases III, IV, V flights 40, 50, 65[b]	
Target Recognition Slant Range (m)	1,000	986 single measurement Flight 61	See Phase I results		2,200	Low = 836; Mean = 1,747; High = 3,233; σ = 604	15 measurements of combined Phases III, IV, V Flights 40, 50, 65	
Sensor Stabilization (gradians)	Not applicable		Not applicable		50	<500 single value measured on flight 64. Imprecise result due to measurement restrictions.		
Automatic Tracking (percent of time inside 2.3-m² target)	Not applicable		Not applicable		95	>95, based on flight 65 laser scoring run at 9:29:20. All observable hits appeared to be within 2.3-m circle for 15-sec duration RPV to target range = 3,142 m (start); 3,425 m (end). Imprecise result because of measurement restrictions.		
Laser Range (m)	Not applicable		Not applicable		Not applicable		Range = 3,000; Accuracy = ±5	3,436 – single point measured on flight 65 (accuracy not measured)
Target Location Accuracy (m) CEP	400	Not measured	Not applicable		400	Not measured	180	CEP = 253 (centroid offset by north 190 and east 83)[c] MRE = 246 (σ = 278) [MRE = 126 see note (d)]
Target Altitude Accuracy (m)		Not measured	Not applicable			Not measured	75	Mean = 71, σ = 87 see note (c) [Mean = 56] see note (d)
Laser Designation Accuracy (percent of time inside 2.3-m² target)	Not applicable		Not applicable		Not applicable		95	>95; see automatic tracking notes

(a) Very few meaningful Phase I results. Two road targets; two field targets; flight 61.
(b) Unless otherwise stated the FOV was not measured. Refer to individual flight tests for more data.
(c) Computed from 26 readings on flight 65.
(d) Three gross location errors discarded because of suspected transient magnetometer errors.

Both target detection and recognition also fell short of the specifications in the few measurements made. This was a result of several factors:

- Hardware problems. At the beginning of the test program, several hardware problems still remained in the vehicle and the sensor. These naturally complicated the job of the sensor operator.
- Range problems. Range coordination problems also existed at the start, which led to the targets being placed incorrectly.
- Considerable image motion. This made searching and identifying with the Phase I sensor very difficult, especially when compounded with the roll-yaw oscillation problem.

The sensor field of view is a parameter that can significantly affect detection and recognition performance. If it is too large, the image motion is not a problem, but resolution of small objects is difficult. If it is too small, the image motion is excessive, and consistent area search becomes impossible. It is felt that an optimum field of view of about 12-deg would give the best compromise.

It is undoubtedly more difficult to find targets with a Phase I sensor. In retrospect, therefore, improved results may have resulted if the Phase I tests could have been performed after Phases III and IV-V, using fully mature hardware, software, and personnel.

4.4.13 Phase II Sensor Test Results

The Phase II sensor embodies both a Phase I unstabilized video camera and a panoramic photographic camera. Photographic camera performance is shown under dynamic resolution and is given as 24 line-pairs/mm. The static resolution of this unit should approach the 75 line-pairs/mm of the actual camera.

The image degradation observed had several contributing factors:

- Focus precision of the camera.
- High rate vibration. This can cause image smear during the 1/2000 sec shutter time.

- Film processing. A gamma value of 1.3 was used for processing. It is recommended that the gamma value be increased to 1.6 to increase contrast and resolution.

No specification has been placed on the dynamic resolution of the camera. The stated goal of 40 line-pairs/mm should be achievable by minimizing the factors mentioned above.

Target detection and recognition with the Phase II sensor was equal to the Phase I sensor as this part of the system is in fact a Phase I video system.

4.4.14 Phase III Sensor Test Results

As previously mentioned, the dynamic resolution was found to be lower than the specification. Reasons for this were discussed in the Phase I results. Except for the laser, the Phase III sensor is essentially identical to the Phase IV-V sensor. The nonlaser data from all Phases III and IV-V flights were therefore combined to give a larger data base for observed results. Data from flights 49, 50, and 65 were combined for these purposes. Using cued targets, detection of both road and field targets generally exceeded the specified requirements. Mean road detection range was computed to be 4,845 m and mean field detection range was 2,282 m. In the target recognition case, the mean figure (1,474 m) is less than the specification (2,500 m); however, several individual readings exceeded this figure. Operator experience with the target area played an important part as well as the degree of recognition attempted. An accepted definition of recognition requires that target to be at least 3 line pairs across the minimum dimension. This is sufficient to detect shape (aspect ratio) and orientation but insufficient to detect identifying features such as gun turrets, wheels, etc.

4.4.15 Phase IV-V Sensor Test Results

All of the laser results shown in the Phase IV-V column of Table 14 were taken from Flight 65, which was the last in the series. This flight demonstrated

considerable operator and equipment maturity. Seven orbits were made during a mission time of 3 hr. Several precise target detections and recognitions were made against a road target, and these data were combined with Phase III data to determine system performance. Twenty-six target location attempts were made against the apex target, the tank mock-up, and Station 48. Burst offset evaluation was attempted but no significant data acquired. After considerable analysis effort and completion of Army flight test evaluations, several errors were uncovered in the burst offset equations and the mechanization of the equations in the software. The required corrections were neither completed nor implemented because of schedule and cost implications.

As previously mentioned, the dynamic resolution remained less than the specification.

Target detection and recognition is as shown in Table 14 under combined Phases III and IV-V data.

Sensor stabilization is extremely difficult to measure in a moving vehicle. Stabilization is intended to compensate for aircraft pitch, roll, or yaw, but does not compensate for the vertical buffeting which can occur. It is almost impossible to separate this kind of vehicle motion from the sensor motion as both contribute directly to the image motion of a distant scene. When attempting to evaluate sensor stabilization, the autotracker cannot be engaged, because it immediately corrects for any sensor or vehicle motion. During Flight 64, some low altitude maneuvers were performed with the sensor pointing straight ahead and slightly down. An attempt was made to determine the sensor stabilization by measuring the movement of the selected FOV center point on the target over a period of about 10 sec. This was estimated to be 3 to 4 ft at a range of between 6,000 and 7,000 ft (approximately 500 μradians). Obviously, therefore, the sensor stabilization is better than this. However, it is impossible to indicate how much better without performing several more specialized flights. The sensor itself is known to have a passive stabilization of 30 μradians; therefore, most image motion observed in this test was probably due to normal aircraft motion.

RPV to target range varied from 1,531 to 3,770 m for the various targets located by using the laser ranger. The accuracy of this measurement is defined by pulse width and rise time of the laser pulse, as well as the digital word quantization. Ground tests have determined the range accuracy of the laser system itself to be ±5 m. Again, this accuracy could not be confirmed by the flight tests because of the relatively low measurement accuracy of the RPV and target locations. The best agreement between laser-measured range and computed range was 18 m.

The centroid of the locations was computed to be at 190 m north and 63 m east of the target, which indicated the possibility of a bias error still remaining in the system. Schedule pressure did not permit any further analysis of this problem. Mean radial error (MRE) from the target was computed to be 248 m with a standard deviation of 378 m. This indicates the major influence of three large errors out of the total 26 readings. If these three large errors are assumed to be caused by transients and are therefore discarded, then the MRE is more realistically 35 m. The altitude error showed better results. The 71 m stated is the average of all 26 measurements and is within the goal of 75 m. Seventeen readings (65 percent) were, in fact, below the 75-m level, and the lowest error was 1 m.

Laser designation at 20 pps was performed several times during Flight 65. This was made against a scoring target that consisted of a large blackboard about 7.3-m square with a 2.3-m white square in the center. A designation pass was selected in which the laser range was consistently greater than 3 km, and the scoring data were analyzed by observing the individual hits over a 20-sec firing period. It was apparent that the center of the laser beam was offset by about 2 m in the upper right hand side of the white target. This could have been caused by a combination of several effects:

- Boresight Error
- Tracking Offset
- Dome Distortion

The total distribution of hits was observed by using the actual laser beam center and counting the hits inside a 2.3-m-diameter circle around this point. Some hit observations were lost when they landed on the black background, which made counting difficult. However, it appeared that all hits were within the 2.3-m circle. The approximate distribution was found to be 60 percent within a 1-m circle, 30 percent within the 2-m ring, and 10 percent in the remaining 0.3-m ring.

Problems encountered with the sensor system elements during development and flight testing are described in section 4.5 of this volume.

4.5 SENSOR PROBLEMS

The Aquila sensor is a highly sophisticated combination of mechanical, electronic, and optical technology. Several problems were encountered during the development program. These problems were all thoroughly investigated, and special tests were devised to gain greater insight. Alternate solutions were then developed and attempted, and the most practical solutions were adopted as permanent engineering changes. In chronological order, the most serious of these problems are described in the following paragraphs.

4.5.1 Camera Resolution

The original video cameras obtained from SRL did not meet the static resolution specification of 450 TV lines. These cameras were returned to SRL for redesign. Also an improved TV monitor (CONRAC) was used for the resolution tests. This improved the results considerably.

4.5.2 Dome Material – Uneven Thickness

This was shown to cause boresighting errors between camera LOS and laser LOS. The major problem was found to be an increase in material thickness at the lower end of the dome. The solution to this problem was to install compensation circuitry, which corrected the tracker center and thereby maintained a

fixed camera-laser LOS boresight over the complete range of elevation angles. The zoom lens was also found to produce small boresight errors over its range, but these were within the specification.

4.5.3 Camera-Dome Mechanical Interference

The original sensor design showed a slight mechanical interference in which the back of the camera scrapes the dome/ring-mount attachment. This problem was solved by beveling the camera housing so it would completely clear the dome at all places.

4.5.4 Gimbal Material

A lightweight synthetic gimbal material (PRD) was investigated as a low-cost replacement for the aluminum design. Several Phase III and Phase IV-V sensors were built with the new material. However, after extensive testing, it was found that this material resulted in boresight shifts due to shift movement of the gimbal housings. The concept may still have application with different types of sensors and different missions. However, there are no current plans to continue this line of investigation.

4.5.5 Video Tracker – Loss of Lock

Early in the development program the video tracker was found to exhibit rapid slewing action following loss of lock. This resulted in operator disorientation, particularly under small FOV conditions (maximum zoom). Design changes were made which resulted in some improvement. Also a time-out circuit was installed, which inhibits the slew drive after 250 ms following lock-loss. This restricts the total slew off the target. This type of centroid tracker also has difficulty in locking onto targets surrounded by clutter. This was particularly noticeable against the road target at station 48 at Fort Huachuca. The track-lock success rate against this target was probably less than 30 percent, whereas

the success rate against the tank mockup or against the laser scoring target at Apex was greater than 80 percent. The latter are field targets in almost zero clutter.

The track stability during track-lock was also influenced considerably by the clutter, with 1 to 3 mradian movement being observed for high-clutter situations such as target 48. Against low clutter targets, the track stability was seen to be excellent and was probably less than 100 μradians.

Operator experience and hardware maturity also affected tracker performance. It is apparent that some skill is required to size and place the tracker box around the tracker in order to maximize the lock success. Furthermore, some trackers performed considerably better than others, which indicated that these were hardware differences. These were investigated and the anomalies uncovvered and corrected, which at least equalized performance. Lock-acquisition and lock-loss remains a problem with these trackers. This is still under investigation.

4.5.6 Dome Damage

The dome is a very fragile part of the sensor. Damage to the domes due to various causes has been a continuing problem. In particular, the domes were found to be cracking in the top rear section. This was investigated and found to be caused by excessive sensor motion on the shock mounts during launch. During this high acceleration period the sensor swings back slightly and impacts against the RPV fuselage. This problem was solved by using styrofoam padding to cushion the rear shock during launch.

4.5.7 Mechanical Cage Problems

The inner and outer gimbals of the sensor are caged mechanically by a drive motor and pin arrangement. During several flights this system failed and jammed the gimbals, thus preventing normal sensor operation. The problem

was thoroughly investigated using high-speed photography and a launch-simulation rig at LMSC-Sunnyvale. It was established that the launch acceleration is sufficient to cause gimbal bending so that the caging pin temporarily disengages and then attempts to re-engage following the initial impacts. Reengagement rarely occurs properly, however, and the gimbals usually move slightly and jam against the caging motor. When commanded, the caging motor then attempts to uncage, but, usually, unsuccessfully. Furthermore the gimbal motors may be commanded to move and overheat by running in the stalled condition. This, in turn, can lead to general overheating, which can affect the camera vidicon performance, and can cause the video to disappear. It was also discovered that the lubricant in the caging motor was clogging the drive and preventing full pin travel.

The sensor caging arrangement was redesigned to provide greater pin engagement length, and a new motor lubricant was specified. This was found to be successful.

4.5.8 Resolver Gear Slippage

The sensor azimuth angle is measured by a shaft resolver that has several bevel gears attached to it. A few cases of gear slippage occurred and contributed indirectly to the mechanical cage problem because it caused azimuth drive even under normal cage conditions. This problem was solved by changing the type of set screw and by using two screws on each bevel gear.

4.5.9 Dome Fogging

The Poise platform was originally designed to be filled with a dry inert gas during operation. However, during most of the flights, the sensor was operated with a regular air environment. Toward the end of the test program, the moisture content in the air was sufficient to cause dome fogging or condensation problems (notably on Flight 65). A decision was therefore made to purge each sensor before flight with dry nitrogen. A certain degree of fogging was still

observed, however, so the nitrogen atmosphere was further improved by the use of dessicant material, which absorbs any remaining moisture. This corrected the problem.

4.5.10 Low Dynamic Resolution

The static resolution of the video camera is 450 TV lines/ph at the center of the screen. This however reduces to 180 to 240 TV lines/ph when it is operated in the RPV and flying over the spatial target at Ft. Huachuca. Several factors contribute to this problem:

- Aircraft motion. A small amount of image smear is caused by any aircraft motion when the forward flight component or pitch and roll are not compensated perfectly by the stabilized platform.
- Data-link bandwidth. This should ideally be greater than 10 MHz to have negligible effect on resolution.
- Aircraft vibration. Shock mounts remove vibration components greater than 30 Hz in frequency. The platform is intended to stabilize any motion in the lower frequencies. Frequency components in the 10 to 30 Hz range may not be totally compensated.
- Ground monitor response. The TV monitor currently used in the Aquila ground station undoubtedly reduces the resolution. This has been established by comparison with other monitors.

4.6 SUMMARY AND CONCLUSIONS

As the flight test program entered Phase B, several Aquila system operational features remained not validated. They were:

- RPV position accuracy. Because of site setup and roll-yaw stability (oscillation) problems
- Dead reckoning navigation. Because of software and hardware problems associated with manual termination of the dead reckoning mode
- Moving box search pattern. Because of intentional scheduling
- Data link at 20-km range. Because of a marginal design

- B modifications to RPVs, GCS, and launcher. Because of need for product improvements
- Cross wind recovery. Because of lack of opportunity
- Standard approach pattern. Because of software evolution problems and student training objectives
- Sensor performance. Because of intentional scheduling

The RPV position accuracy was validated during B flights after a revised antenna correction factor was determined for inclusion into the software. The correction factor was calculated from updated site survey data supplied by Fort Huachuca Range Operations, as well as prior flight history. The roll-yaw stability problem, when flying away or toward (east-west) the GCS at extended range, continued to be a problem throughout the Phase B flight test program. (Refer to sections 4.4.4, 4.4.6, and 4.4.7 of this volume for a detailed discussion of the problem.) Attainment of accuracy requirements was demonstrated along north-south legs where RPV antenna pattern polarization effects were minimal.

Dead-reckoning navigation was not validated during Phase B because of the need for a circuit modification within the flight control electronics package. A hardware incompatibility had been discovered late in the program, which did not allow manual termination (from the GCS) of the dead-reckoning mode in case of an errative flight path. Consequently, Army and LMSC program management decided to forego the required validation.

The moving box search pattern was never demonstrated during an RPV flight, by mutual agreement with the Army, because the software had been demonstrated with the squared S search pattern. The moving box search pattern is a minor variation of the squared S pattern in that the second leg proceeds in the opposite direction and requires merely a sign change when the program is entered into the computer. The basic moving box concept was verified successfully in the simulator mode, however.

Data-link performance to a range of 20 km at an altitude of 1,000 to 2,000 ft AGL was demonstrated successfully on several sensor and check flights to the east range. The B modifications to the rf system were therefore validated.

Cross wind recovery opportunities near the upper limit of the design envelope (20 knots, gusts to 35 knots) were sparse. However, during Flight 43, a cross wind of 35 km/h (18 knots) from an angle of 65 deg across the approach path developed (refer to Figure 37), and the RPV was recovered successfully.

Two standard approach patterns were developed in the software for use at Fort Huachuca. The pattern used most often for student training purposes was 1 by 3 km. This pattern gave the student sensor operator sufficient time to track the RPV before selecting the final approach mode. The second approach pattern developed in the software was 1 by 2 km for use in areas limited in airspace because of surrounding mountains. When loading the computer prior to a mission, the RPV operator must answer the software question "Training flight (Y or N)." a "yes" answer will yield the larger approach traffic pattern.

Figures 25, 28, and 29, and Table 11 indicate the planned Otter and RPV flights for Phase B of the flight test and validation program.

RPV flights were made with each type of sensor, and data were obtained for each of the following sensor system objectives:

- Target detection and recognition with a stabilized sensor
- Target detection and recognition with an unstabilized sensor
- Autotrack with the stabilized sensor
- Photo-reconnaissance
- Target location
- Target designation (with scoring)

Tables 15 through 18 summarize the various targeting system performances.

TABLE 15. AQUILA TARGETING SYSTEM PERFORMANCE SUMMARY – PHASE I

KEY SYSTEM DESIGN CHARACTERISTICS

- 2-axis gimballed TV with remote FOV, focus, iris controls
- ±0 to 170 deg azimuth and +10 to −60 deg elevation ranges
- Two fixed gimbal slew rates
- 4 to 37 deg FOV range

SPECIFICATION	REQUIREMENT	MEASURED VALUES
• Detection range		
– Road	3000 m (50% Prob.)	2160 m[(a)]
– Field	1500 m (50% Prob.)	1135 m[(a)]
• Recognition range	1000 m (50% Prob.)	940 m[(a)]
• Resolution	>200 TVL/frame	180 TVL/frame

APPLICABLE TEST FLIGHTS

Flight No.	RPV No.	Date
43	014	3 June 1977
45	014	10 June 1977
47	014	14 June 1977
61	014	7 June 1977

RESULTS EXPLANATION

- Excessive image motion due to RPV motions
- Nonstabilized video platform
- Nonproportional gimbal controls

SUMMARY

- Narrow FOV operation with excessive aircraft motion has little utility
- Motion on video monitor was distracting to operator
- Good video quality for smooth air, wide FOV operation
- Data-link induced oscillations reduced sensor effectiveness

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(a) Best single-point measured values

TABLE 16. AQUILA TARGETING SYSTEM PERFORMANCE SUMMARY – PHASE II

KEY SYSTEM DESIGN CHARACTERISTICS

- 35-mm Minipan panoramic camera, 225-ft film capacity
- Remotely controlled frame rates of 4, 2, and 1 frames/sec and 2, 3, 4, 5, 10, and 13.5 sec/frame
- 180 deg crosstrack × 34-deg alongtrack frame field
- High shutter speeds (1/4000 to 1/500 sec)
- Frames remaining count at GCS
- Normally comounted with Phase I poise
- Post-mission data dump for photographic identification of mission conditions (e.g., location, time, and altitude)

MEASURED SYSTEM PERFORMANCE

- Multi-frame-rate control capability demonstrated
- Basic photographic ground mapping performance demonstrated, utilizing computer-controlled search patterns
- Quantitative performance good

APPLICABLE TEST FLIGHT

Flight No.	RPV No.	Date
47	014	14 June 1977

RESULTS SUMMARY AND EXPLANATION

- Satisfactory camera operation
- Good Photographic quality (photographics slightly overexposed)
- Improper frames remaining counter operation (easily corrected)
- Computer dump not correlated to photographics (frame count problem)
- Additional flight test desirable

TABLE 17. AQUILA TARGETING SYSTEM PERFORMANCE SUMMARY – PHASE III

KEY SYSTEM DESIGN CHARACTERISTICS

- 2-axis gimballed TV with remote FOV (4 to 37 deg), focus, filter
- 360 deg azimuth, +10 to -90 deg (nadir) elevation ranges
- Proportional slew rate control, two rate ranges
- Automatic light compensation
- Rate stabilized line of sight (LOS)
- Contrast centroid autotracker – light-on-dark and dark-on-light discrimination, contrast enhancement
- LOS and elevation angles displayed

SPECIFICATION ITEM	REQUIREMENT	MEASURED VALUES
• Detection range		
– Road	5000 m (50% Prob.)	>4845 m mean
– Field	2500 m (50% Prob.)	>2282 m mean
• Recognition range	2200 m	>1747 m mean
• Resolution	>300 TVL/frame	250 TVL/frame
• Stabilization	50 μradian rms/axis	<500 μradians field test[a]
• Autotrack	LOS in 2.3 × 2.3 m target at 2.5 km 95% of track duration	Demonstrated in Phase IV-V by laser scoring

APPLICABLE TEST FLIGHTS

Flight No.	RPV No.	Date
49	014	19 May 1977
50	014	21 May 1977

(a) estimate only

TABLE 17. (Cont.)

RESULTS SUMMARY AND EXPLANATION

- Detection-recognition results based on both operator and data reduction process
- Military truck targets on Fort Huachuca east range
- Sensor demonstrated capabilities greater than specification requirements
- Further testing against well-defined road and field targets required to adequately bracket full capabilities
- Targets were cued

TABLE 18. AQUILA TARGETING SYSTEM PERFORMANCE SUMMARY – PHASE IV-V

KEY SYSTEM DESIGN CHARACTERISTICS

- Detection and recognition results as given in Table 17, Phase III chart
- Same video sensor properties and performance as Phase III
- Boresighted Nd:YAG laser
- Self-erecting vertical gyro mounted on sensor package
- Target location and altitude derived from sensor parameters (e.g., gimbal and RPV angles, range) and RPV position
- Burst offset derived from sensor parameters and cursor offset
- Target location and altitude displayed on video scope
- Burst offset and target range displayed on control panel

SPECIFICATION ITEM	REQUIREMENT	MEASURED VALUES
• Target location (GCS→RPV = 20 km) (RPV→TGT >2 km)	100 m CEP	253-m CEP (248 m MRE) based on 26 Flight 65 measurements 135-m MRE[a]
• Target altitude	75 m (50% Prob.)	71 m (avg. of 26 Flight 65 measurements)
• Burst offset	25 m (50% Prob.)	Not demonstrated (software problem)
• RPV to target laser range	3000 m	3425-m single point measurement[b]
• Laser designation (2.3 × 2.3 m target)	90% of spot on target 95% of time at 2.5 km	Achieved

RESULTS SUMMARY AND EXPLANATION

- Autotracker and designator performance appeared to be outstanding with adequate contrast target
- Target location and range values based on post-flight corrections for known equation errors
- Tank target >20 km; others slightly less
- No location degradation during loiter patterns
- Target altitude performance improved with time during flight – unknown cause
- Further controlled conditions desirable to bracket performance

(a) Three large errors assumed caused by transients were discarded. MRE computed from remaining 23 results.
(b) Accuracy requirement of ±5 m not verified.

Army student "hands-on" training was also of paramount importance during these flights and, on conclusion of the test series, both the Fort Sill and Fort Huachuca Army teams were certified. The two Army teams then entered their respective test programs. Artillery adjustment was performed by the Army during the series of flight tests by the Fort Sill Army team.

At the conclusion of Phase B tests, several sensor problems required additional resolution. They include:

- Uncaging problem. Caused by launch load forces placed on the sensor gimbals
- Dome cracking during launch. Caused by launch forces on the entire sensor assembly
- Tracking instability in certain trackers. Resulted from improper alignment adjustment at Honeywell
- Sensor overheating. Resulted in video blackout after some time in flight
- Dome fogging in flight. Caused by moist air condensation inside the dome

After the required modifications were identified, a schedule was established for sensor rotation back to the Honeywell factory for repair and modification. Dome fogging was reduced greatly by purging the sensor with dry nitrogen and adding desiccant material in the dome cavity. The dome-cracking problem was minimized by the temporary addition of polyurethane foam filler material between the sensor and bulkhead immediately aft. The uncaging problem was solved by redesigning the sensor cage drive to use a longer caging pin. The cage drive motor no longer generated excessive heat (while jammed) that could be conducted to the vidicon, and the vidicon overheating problem was also rectified. Table 19 summarizes the sensor demonstration program conclusions.

TABLE 19. SENSOR DEMONSTRATION PROGRAM CONCLUSIONS

PHASE I

- Utility limited without stabilization because of excessive image motion (based on limited data)

PHASE II

- Minipan camera operation well established in prior programs
- Frame count and mission parameter printout should be retested following minor software and GCS modifications
- Camera operation in dead reckoning mode remains to be tested

PHASE III

- Good video quality and LOS stabilization
- Video tracker performance needs improvement on some units
- System will be very effective in battlefield reconnaissance missions

PHASE IV, V

- Target location/altitude accuracy appears satisfactory (based on post-flight analysis)
- Minor software modifications required to achieve accurate real-time performance
- Burst offset accuracy not demonstrated because of software errors
- Target designation performance satisfactory

No major operational problems were evident with either launcher on conclusion of the Phase B test and validation program. Difficulties did arise as late as the end of the program with the launch-speed measurement system, however, because of a combination of display-reliability and magnetic pickup adjustment problems. The basic design concept was validated. A theoretical air-dryer-system limitation was discussed with the Army; however, since the problem had not appeared at Fort Huachuca, further studies were not funded.

The retrieval system had one open concern item. A safety pin in the holdback braking system had deformed and broken under the strain of high winds, resulting in collapse of the retrieval net. Temporary extra safety wires were added to reinforce the brakes. The supplier, All American Engineering, was notified and sent redesigned parts to Fort Huachuca in November 1977. No additional problems were reported.

The roll-yaw stabilization problem was not resolved adequately during Phase B. Many attempts at minimizing the problem by limiting heading rate commands in the software transpired. Elimination of the contribution of antenna polarization could require a two-axis tracking antenna at the GCS. Such a redesign was beyond the scope of this program. GCS-002 was fully validated at the conclusion of the test program. GCS-001 required additional troubleshooting and demonstration flights and was validated soon thereafter.

Table 20 lists the conclusions of the overall system as a result of the flight demonstration program. The potential to increase the U.S. Army's target acquisition capability with an RPV system was clearly demonstrated.

TABLE 20. DEMONSTRATION PROGRAM OVERALL SYSTEM CONCLUSIONS

- U.S. Army personnel without prior qualified pilot skills were trained to operate the various RPV system elements.
- Checkout of RPV autopilot loops by the GCS computer utilizing a software test routine was routinely demonstrated.
- A mobile, catapult-type RPV launcher was demonstrated to be reliable in its primary function with a minimal crew size.
- Automatic waypoint guidance, search, loiter, and final approach concepts were successfully demonstrated.
- Manual takeover in flight to allow changes to preplanned waypoints was routinely demonstrated.
- Many off-the-shelf commercial grade component parts, subassemblies, and assemblies used in the GCS had not been designed for the wide range of temperatures, shock, and vibration environments encountered during the field test program and were, consequently, of less than desirable reliability.
- Sensor stabilization enhances target detection, recognition, and tracking.
- Targets of poor contrast to the background reduced the effectiveness of target autotracking.
- Laser designation of a target from an RPV platform was successfully demonstrated.
- Rapid reorientation of the launch and retrieval directions to accommodate wind-direction changes was routinely demonstrated.
- Configuration of the Aquila RPV system was not conducive to rapid site relocation.

Table 20. Continued.

- **Dead-reckoning and burst offset were not adequately demonstrated, because of formulation and software implementation errors that would have caused unacceptable program impacts to correct.**

- **The ability to manually slew the GCS antenna to reacquire the RPV after anomalous data-link performance was a distinct advantage.**

- **The RPV met performance specifications in maximum range (20.5 m), maximum altitude (12,000 ft), and endurance (3 hr).**

- **Performance of the RPV was below specification requirements in weight, time-to-climb to 12,000 ft, and maximum airspeed.**

Appendix A

ENGINEERING MEMORANDUM*

TITLE: AQUILA SYSTEM VALIDATION FLIGHT TEST PLAN

EM No. 5583-50
WBS No.:
DATE: 30 Jul 76

AUTHORS: G. S. McCarthy

APPROVAL:
Grover L. Alexander
ENGRG:
SYS. ENGRG:
N. G. Tosch

I. PURPOSE

The purpose of this Engineering Memorandum is to define the flight test requirements for the Aquila Validation Program, and to provide the basis for Flight Test planning to validate these requirements.

II. FLIGHT TEST REQUIREMENTS

The overall approach for achieving Aquila System Validation is defined in Figure A-1. The objectives of Phase A are to demonstrate system functions and performance capabilities and to validate system test and operating procedures. Sensor performance and typical missions will be demonstrated in Phase B to validate the system mission capability. In Phase C, Army personnel will check out the system and conduct mission operations as the final step in Phase I System Validation.

Figures A-2 through A-12 are a series of Logic Flow Charts which depict the sequence to be followed and the parameters to be evaluated during Phase A to validate each of the required Aquila system functional and performance capabilities. Primary emphasis has been given toward developing a minimum-risk

*Lockheed Missiles & Space Company, Inc., Tactical Systems Engineering

approach leading to validation of each of the system capabilities. Table A-1 is a summary of objectives for each flight for Phase A of the Flight Test Program.

Tables A-2 through A-5 are the detailed requirements for flights 014, 015, 016, and 017 respectively. The actual flight plans will be prepared from these requirements. Requirements and flight plans will be prepared for three flights in advance. This scheduling will allow for the updating of the plan for flight 018 and subsequent flights, based upon previous flight results and achievements. Flights 018, 024, 026, and 027 are contingency flights. These flights will be utilized to insure the validation of test objectives from earlier flights which were either not completed or the data obtained was questionable.

Figure A-13 is the logic flow chart for the system mission capability validation, Phase B of the Validation Program. Table A-6 depicts those flights required for Phase B validation.

Figure A-14 is the logic flow chart for the Aquila System Validation with an Army flight crew, Phase C of the Program. Table A-7 depicts those flights required for Phase C validation.

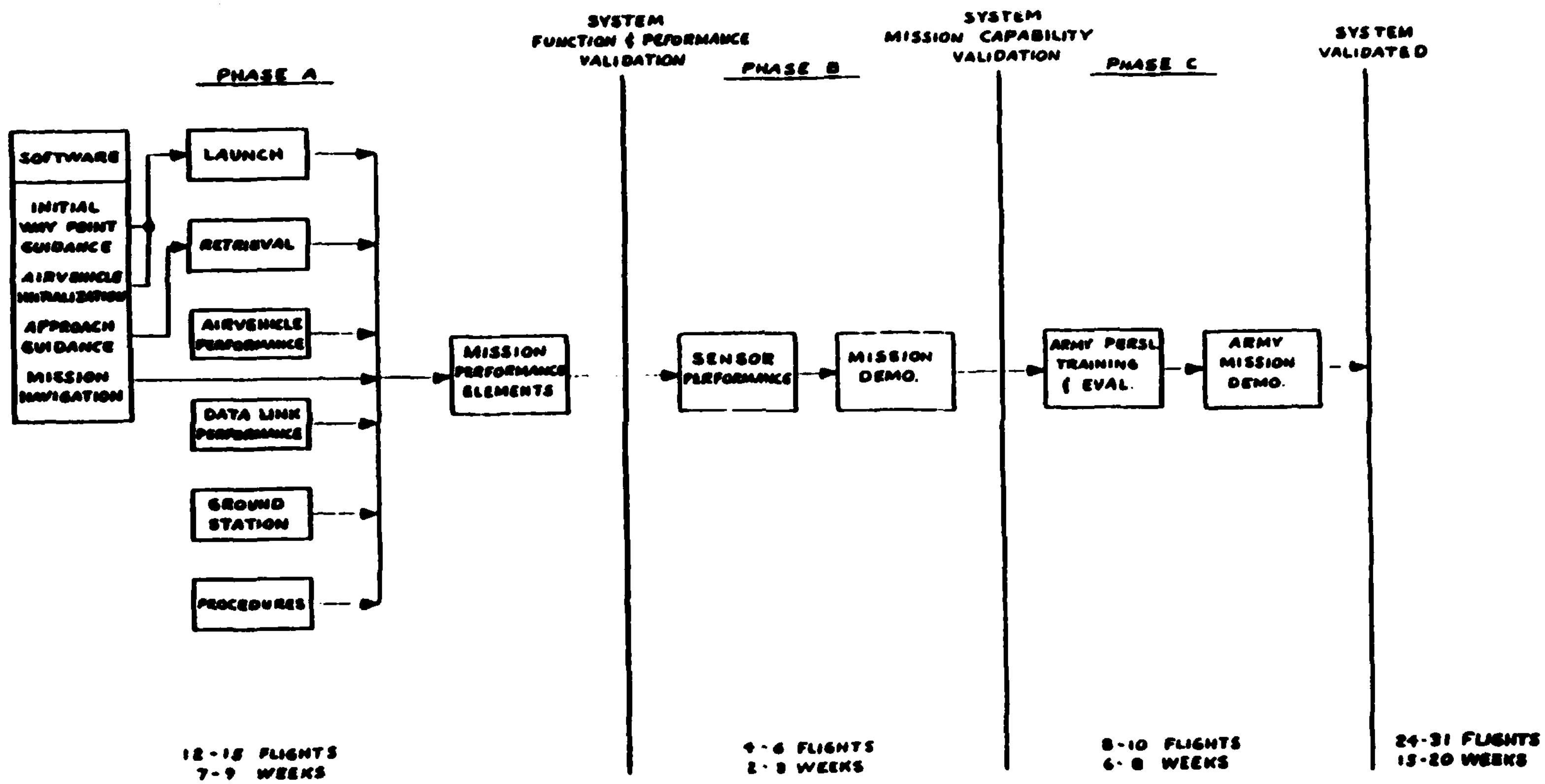

Figure A-1. Validation Program

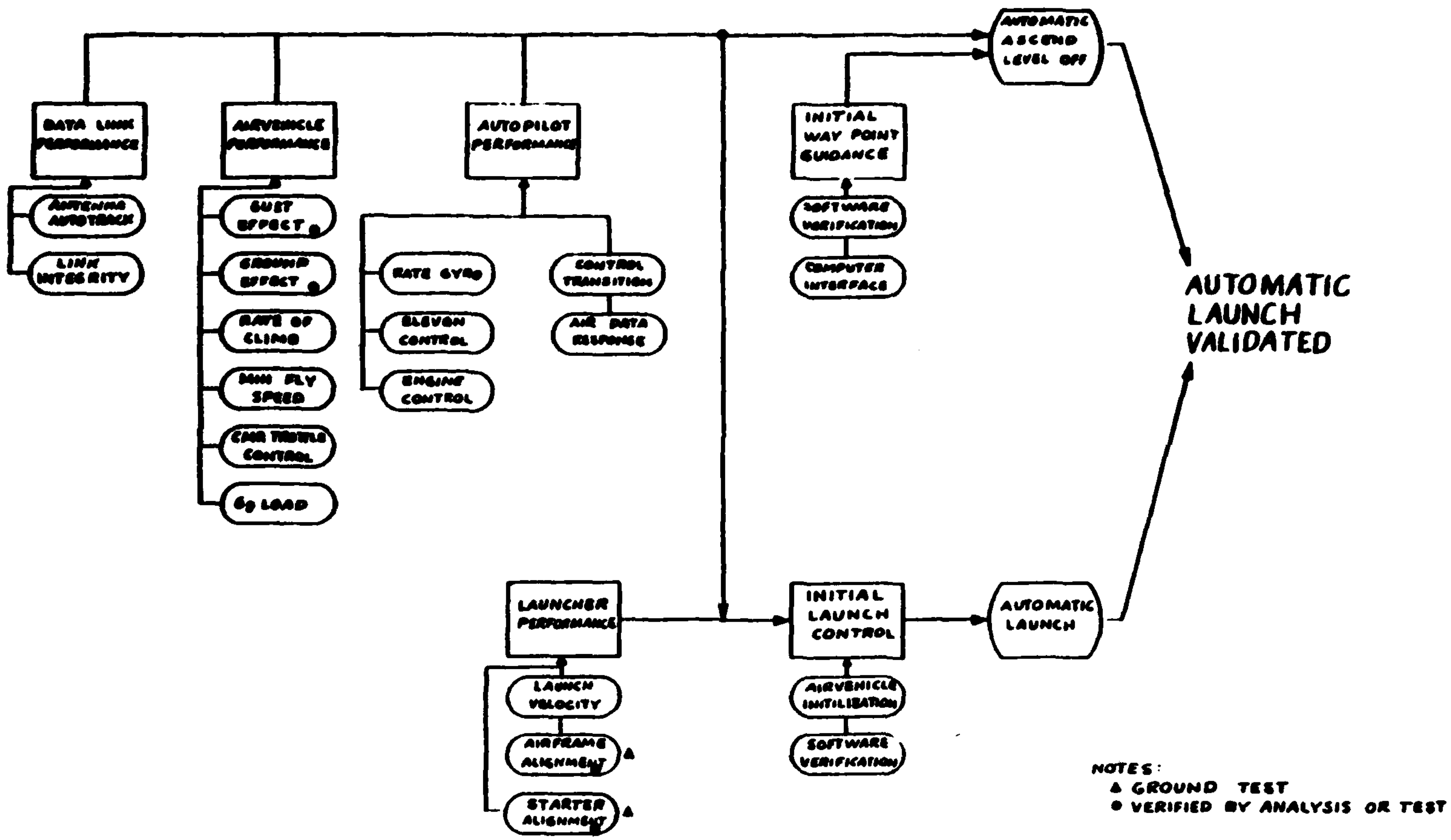

Figure A-2. Launch Validation Phase A

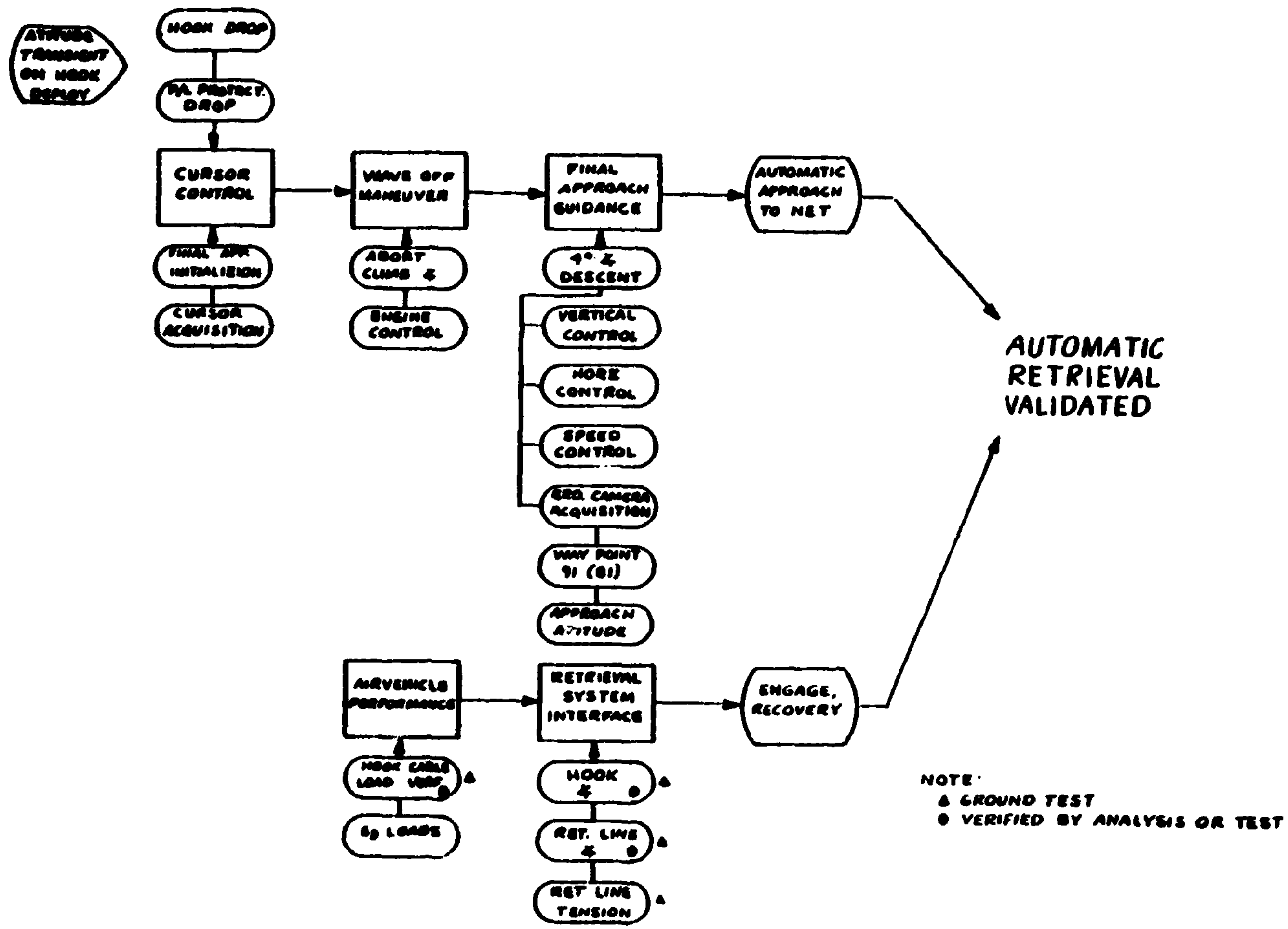

Figure A-3. Retrieval Validation Phase A

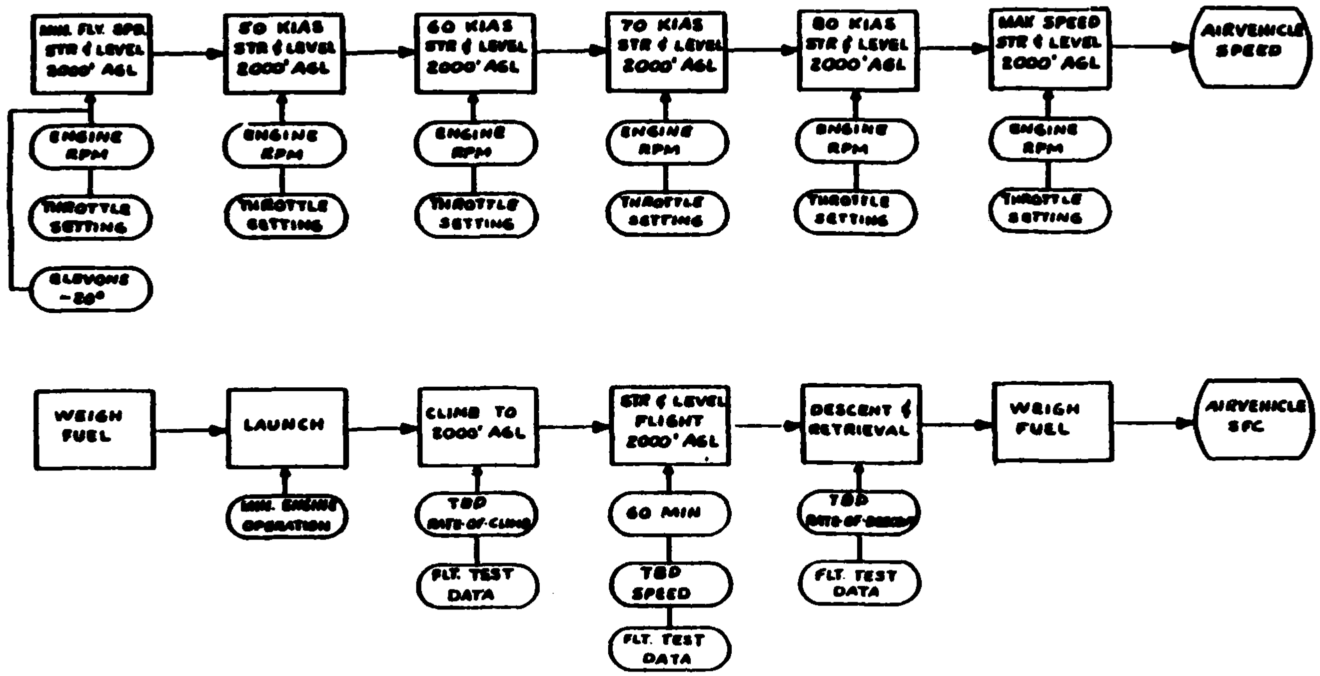

Figure A-4. Airvehicle Performance Phase A

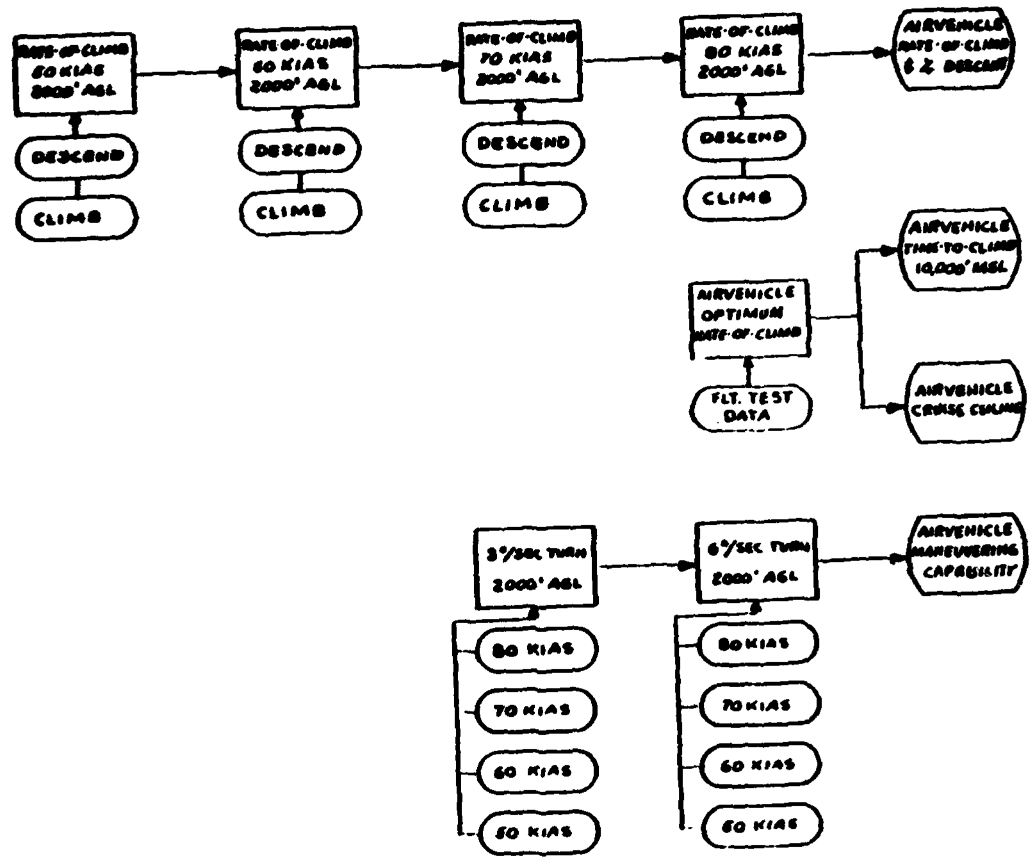

Figure A-4. (Cont)

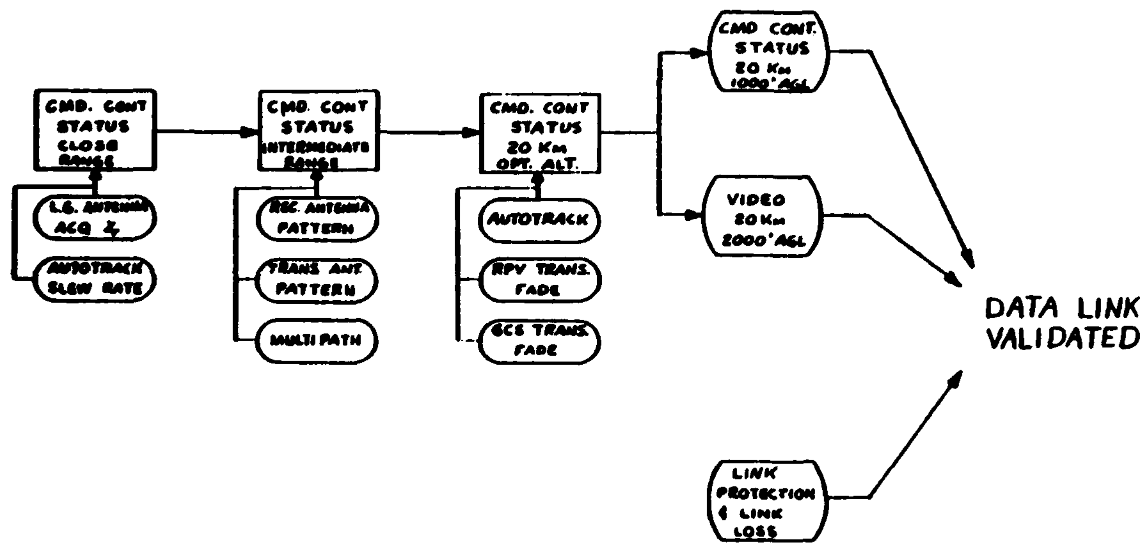

Figure A-5. Data-Link Validation Phase A

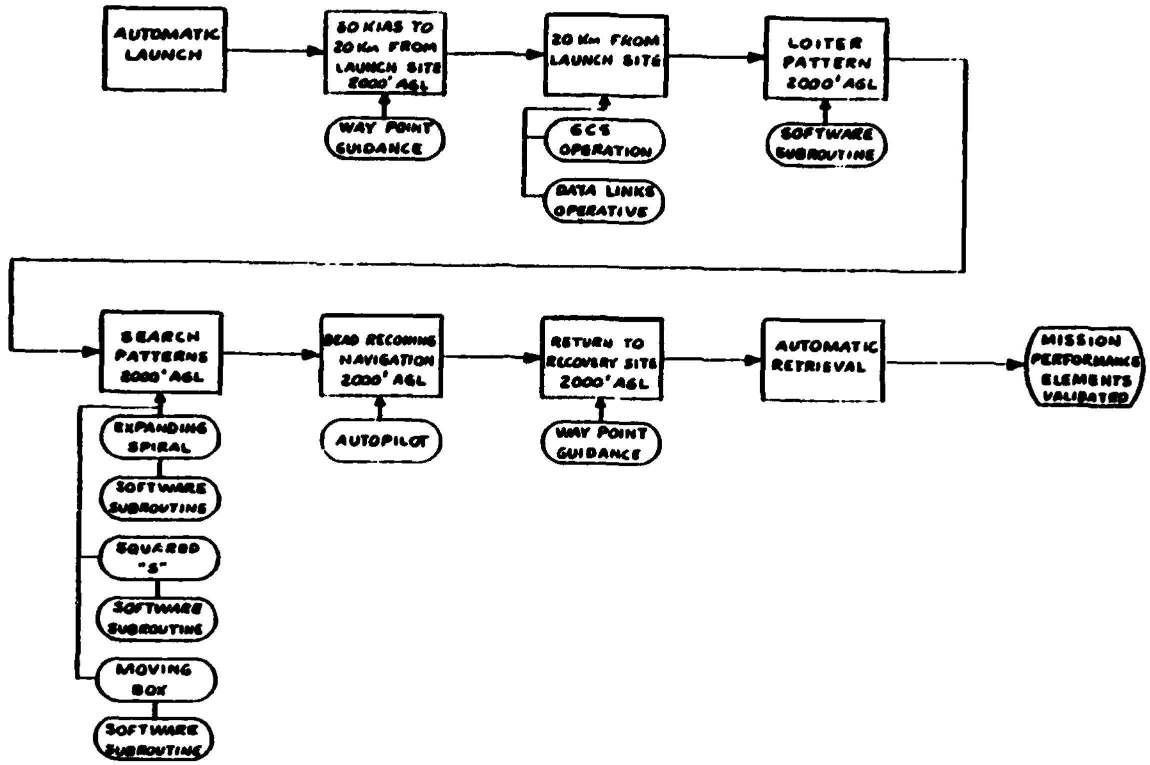

Figure A-6. Mission Performance Validation Phase A

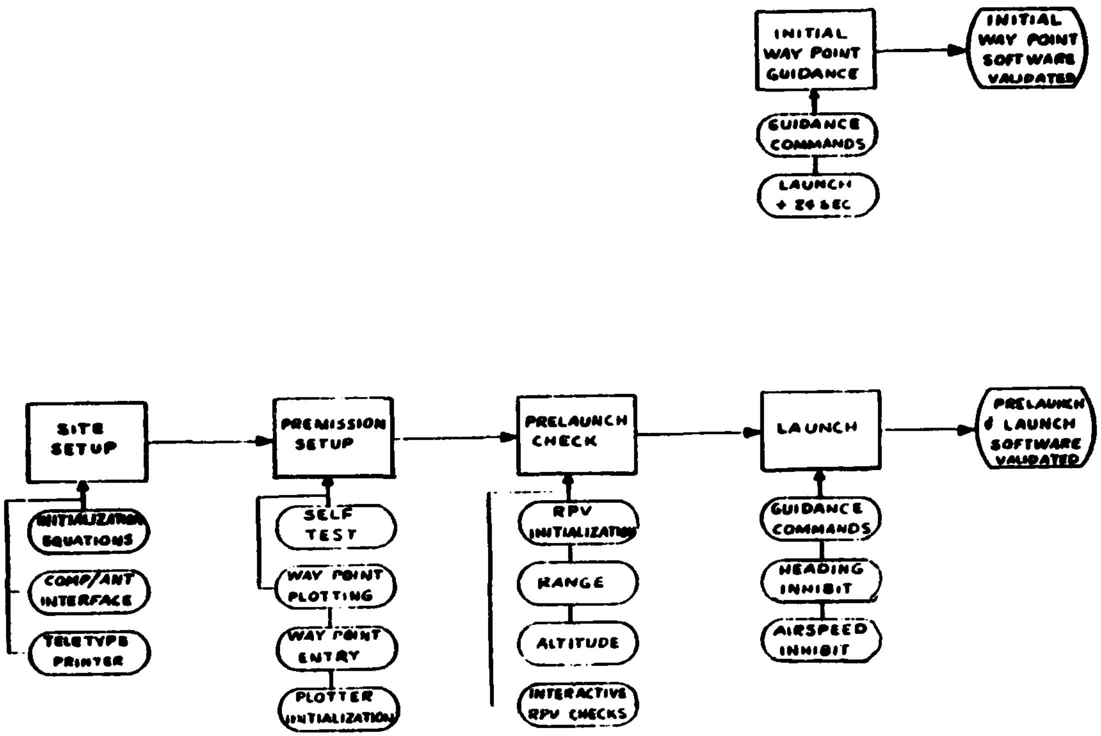

Figure A-7. Software Validation Phase A

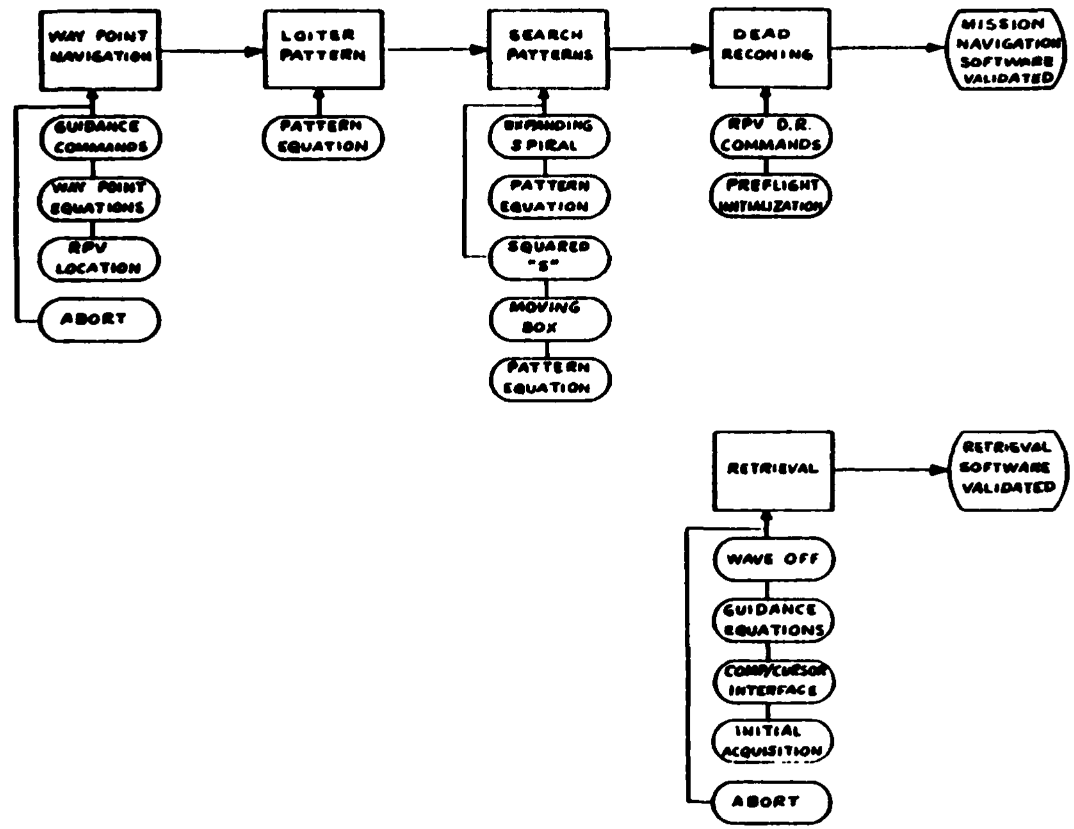

Figure A-7. (Cont)

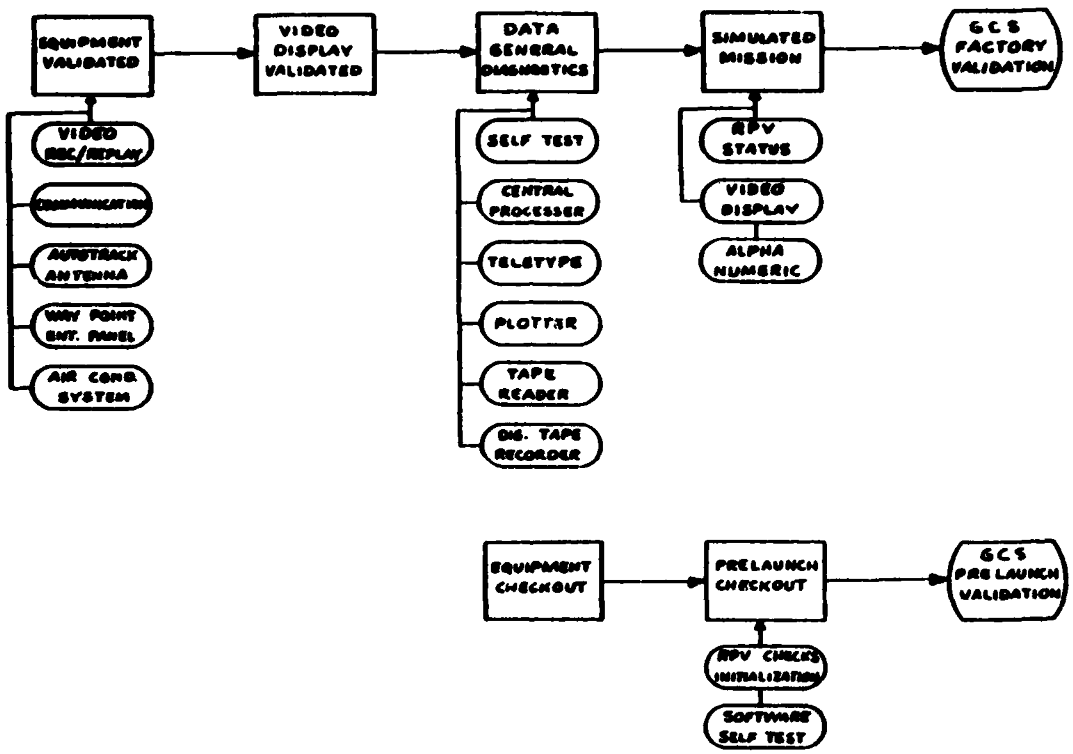

Figure A-8. Ground Control Station Validation Phase A

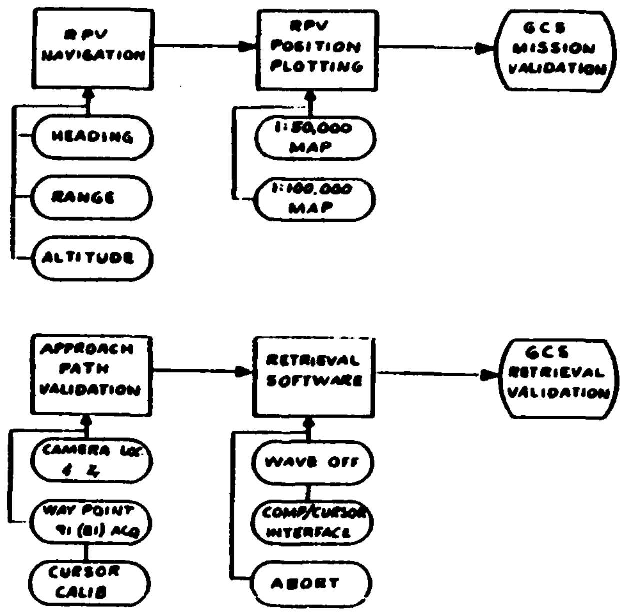

Figure A-8. (Cont)

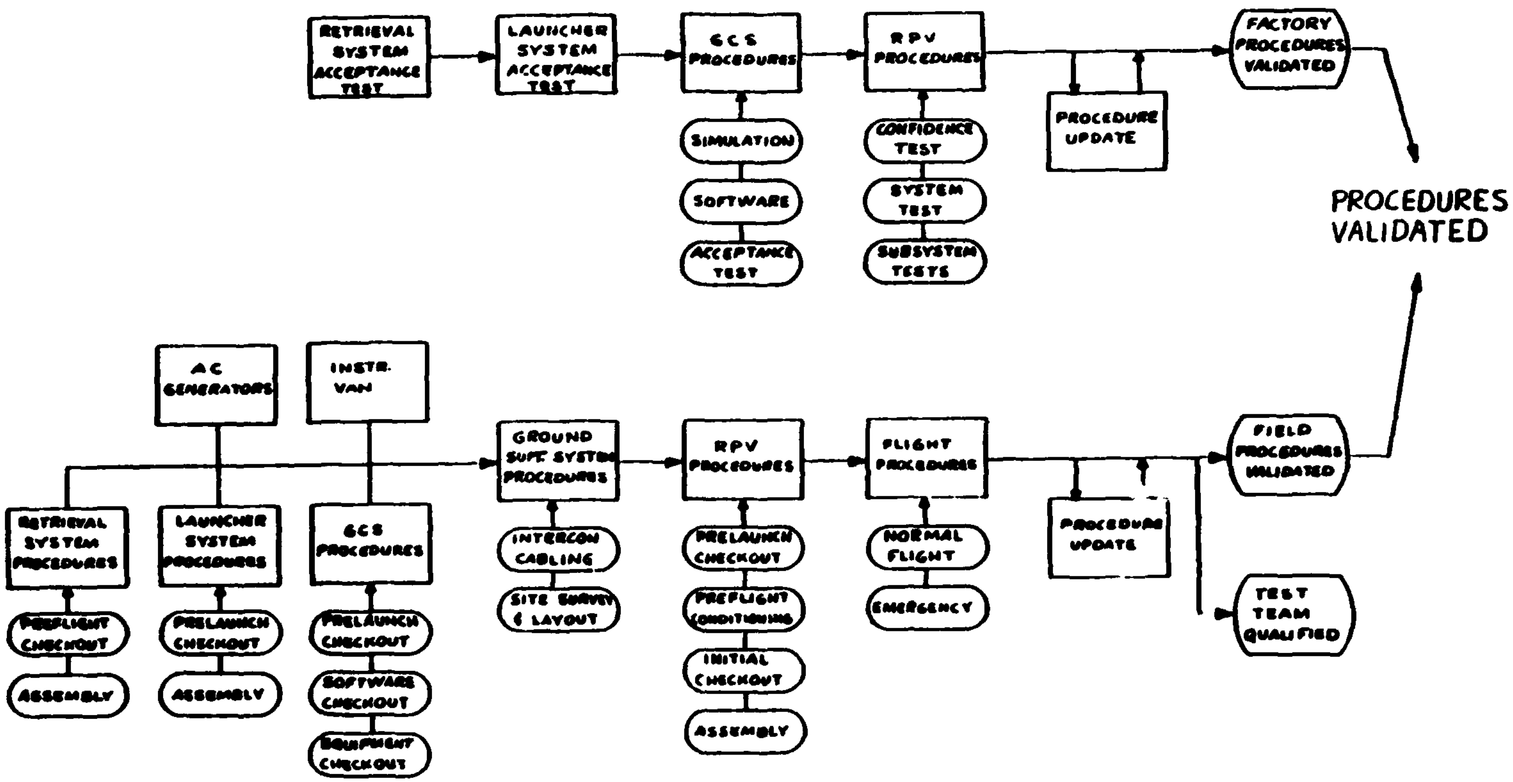

Figure A-9. Procedure Validation and Test Team Qualification Phase A

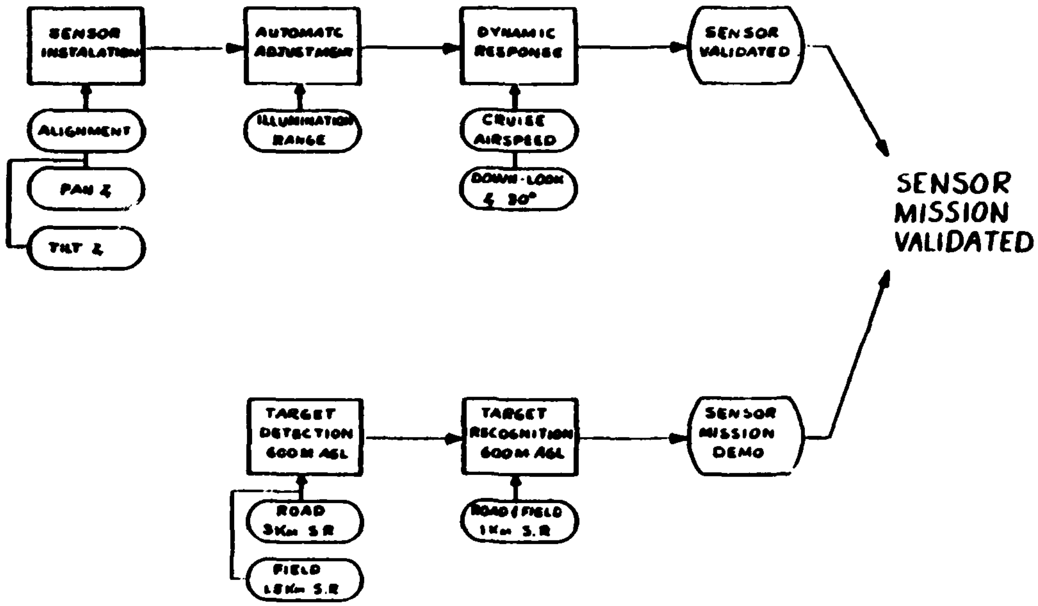

Figure A-10. Sensor Mission Validation Phase B

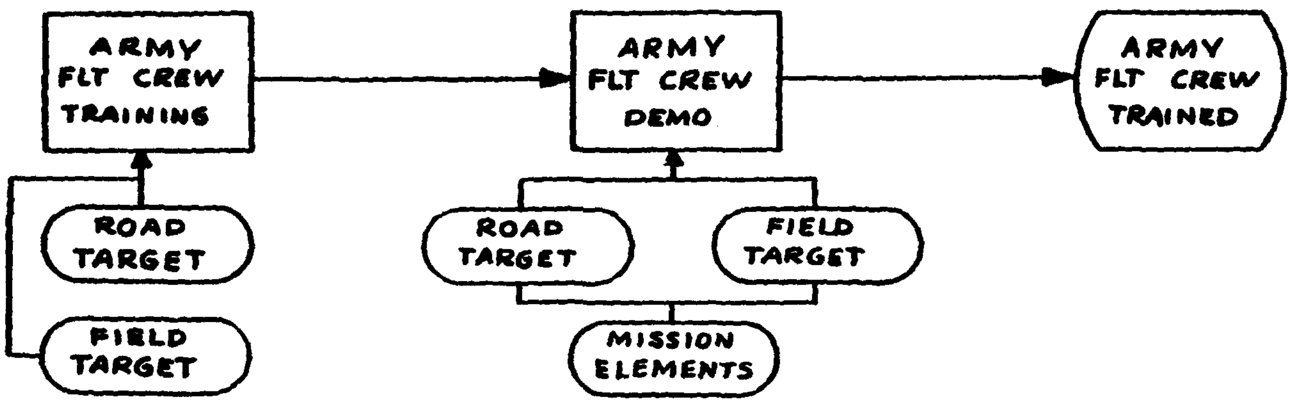

Figure A-11. Army Training and Flight Demonstration Phase C

TABLE A-1. AQUILA PHASE A VALIDATION PROGRAM

PROGRAM ELEMENT	14	15	16	17	18 ▲	19	20	21	22	23	24 ▲	25	26 ▲	27 ▲	
AUTOMATIC LAUNCH				●	●	●	●								
DATA LINK PERFORMANCE	●	●	●												
AIRVEHICLE PERFORMANCE		●	●		AUTOMATIC										AUTOMATIC
AUTOPILOT PERFORMANCE		●	●		LAUNCH										LAUNCH
INITIAL WAY POINT GUIDANCE			●												VALIDATED
LAUNCHER PERFORMANCE	●	●	●												
INITIAL LAUNCH CONTROL			●												
AUTOMATIC RETRIEVAL					●	●	●	●							
CURSOR CONTROL		●	●	●											AUTOMATC
WAVE OFF MANEUVER		●	●	●	AUTOMATIC										RETRIEVAL
FINAL APPROACH GUIDANCE			●	●	RETRIEVAL										VALIDATED
AIRVEHICLE PERFORMANCE		●	●	●											
RETRIEVAL SYSTEM INTERFACE	●	●	●	●											
AIRVEHICLE PERFORMANCE															
SPEED		●	●												
MANEUVERING CAPABILITY		●	●												AIRVEHICLE
RATE OF CLIMB AND DESCENT				●											PERFORMANCE
SPECIFIC FUEL CONSUMPTION								●							VALIDATED
TIME TO CLIMB TO 10,000' MSL									●						
CRUISE CEILING									●						
DATA LINK															
CMD. CONTROL STATUS - CLOSE RANGE	●	●	●	●	●	●	●	●		●					DATA
CMD. CONTROL STATUS - INTER RANGE									●						LINK
CMD CONTROL STATUS - LONG RANGE												●			VALIDATED
VIDEO STATUS - LONG RANGE												●			
LINK PROTECTION AND LOSS	●	●													
MISSION ELEMENT PERFORMANCE															
WAY POINT GUIDANCE		●	●	●		●	●		●			●			
LOITER PATTERN							●		●			●			MISSION
SEARCH PATTERN - EXPANDING SPIRAL							●								PERFORMANCE
SEARCH PATTERN - SQUARED "S"												●			ELEMENTS
SEARCH PATTERN - MOVING BOX									●						VALIDATED
DEAD RECKONING NAVAGATION										●					
SOFTWARE															
PRELAUNCH AND LAUNCH			●	●	●	●	●								
INITIAL WAY POINT			●	●	●	●	●								SOFTWARE
WAY POINT NAVIGATION						●									VALIDATED
LOITER PATTERN							●		●						
SEARCH PATTERNS							●		●						
DEAD RECKONING										●					
RETRIEVAL			●	●	●	●	●	●							
GROUND CONTROL STATION															
DATA GENERAL DIAGNOSTICS	●														GROUND
PRELAUNCH CHECKOUT		●	●	●	●	●	●								CONTROL
RPV NAVIGATION						●	●	●	●						STATION
RPV POSITION PLOTTING			●			●	●	●	●						VALIDATED
APPROACH PATH			●	●											
PROCEDURES															
SITE SURVEY AND LAYOUT	●														
LAUNCHER SYSTEM	●	●	●	●	●	●	●								
RETRIEVAL SYSTEM	●	●	●	●	●	●	●	●							PROCEDURES
GROUND CONTROL STATION	●	●	●	●	●	●	●	●	●						VALIDATED
RPV CHECKOUT AND CONDITIONING	●	●	●	●	●	●	●	●	●	●					
FLIGHT TEST PLAN	●	●	●	●	●	●	●	●	●	●	●	●			
EMERGENCY (AS REQUIRED)															
TEST TEAM															
LAUNCHER SYSTEM OPERATION	●	●	●	●	●	●	●								TEST
RETRIEVAL SYSTEM OPERATION	●	●	●	●	●	●	●	●							TEAM
GCS OPERATION	●	●	●	●	●	●	●	●	●						QUALIFIED
RPV OPERATION	●	●	●	●	●	●	●	●	●	●					
FLIGHT REHEARSAL	●	●	●	●	●	●	●	●	●	●	●	●			

▲ CONTINGENCY FLIGHT

TABLE A-2. AQUILA PHASE A FLIGHT 014

FLT PHASE	MODE	OBJECTIVES	FLT PROFILE	DATA REQ.
LAUNCH	R/C	ANTENNA AUTOTRACK	CLIMB TO $\geq$ 300M	TLM
		AIR DATA RESPONSE	AGL	H.S. PHOTO
		LAUNCHER PERFORMANCE		METEORLOGICAL
CRUISE	MANUAL A/P	AUTOPILOT FUNCTIONS	$\leq$ 1 KM FROM GCS	TLM
		CONTROL SURF. RESP.	V = 130 KMIAS	
RETIREVAL	R/C	ATITUDE TRANSIENTS	DEPLOYMENT	TLM
		HOOK & P/L PROT. DEPLOY	$\geq$ 300M AGL	H.S. PHOTO
		HOOK ENGAGEMENT	V = 90 K_MIAS	METEORLOGICAL
		NET RETRIEVAL		
GENERAL		DATA LINK PERFORMANCE		
		TEST TEAM PERFORMANCE		
		PROCEDURAL ADEQUACY		

TABLE A-3. AQUILA PHASE A FLIGHT 015

FLT PHASE	MODE	OBJECTIVES	FLT PROFILE	DATA REQ
LAUNCH	R/C	CONTROL TRANSITION	CLIMB TO	TLM
		INITIAL RATE OF CLIMB	300M AGL	H.S. PHOTO
		ANTENNA AUTOTRACK		METEOROLOGICAL
		AIR DATA RESPONSE		
		LAUNCHER PERFORMANCE		
AIR VEHICLE	MANUAL A/P	90 AND 130 KM IAS	V AS STATED	TLM
PERFORMANCE		STR. & LEVEL	600M AGL	600M AGL AIR TEMP
		ENGINE RPM	RACETRACK WITH	GCS VIDEO
		THROTTLE SETTINGS	STR. LEG $\geq$ 2 KM	
		30/SEC TURNS		
		90° AND 180°		
		MIN FLY SPEED	V = MIN CONT. SPEED	
		STR. & LEVEL	600M AGL	
		ENGINE RPM	RACETRACK WITH	
		THROTTLE SETTING	STR. LEG $\geq$ 2 KM	
		ELEVON POSITION		
		MAX FLY SPEED	V = MAX	
		STR. & LEVEL	600M AGL	
		ENGINE RPM	RACETRACK WITH	
		THROTTLE SETTING	STR. LEG $\geq$ 2 KM	

TABLE A-3. (CONT)

FLT PHASE	MODE	OBJECTIVES	FLT PROFILE	DATA REQ.
AUTOMATIC	APP. GUIDANCE	COMP/CURSOR I/F	STR $\geq$ 3 KM	TLM
RETRIEVAL		CURSOR CONTROL	V = 90 KM IAS	GCS VIDEO
INITIALIZA-		WAYPOINT 91 (81) ACQ	450M AGL	FPS-16 RADAR
TION		APP. GUID. FUNCTIONS		
		WAVE OFF		
		ABORT		
RETRIEVAL	R/C	HOOK ENGAGEMENT		TLM
		NET RETRIEVAL		H.S. PHOTO
				METEORLOGICAL
GENERAL		DATA-LINK PERFORMANCE		TLM
		AIR VEHICLE DATA		GCS PLOTS
		TEMPERATURES		GCS VIDEO
		BUS VOLTAGE		GCS TAPES
		CONTROL SURF. POSITION		
		GCS OPERATION		
		RPV LOCATION		
		RPV PLOTTING		
		VIDEO		
		TEST TEAM PERFORMANCE		
		PROCEDURAL ADEQUACY		

TABLE A-4. AQUILA PHASE A FLIGHT 016

FLT PHASE	MODE	OBJECTIVES	FLT PROFILE	DATA REQ.
LAUNCH AND	R/C	ANTENNA AUTOTRACK	CLIMB TO SAFE	TLM
ESTABLISH HEADING		AIR DATA RESPONSE	MANEUVERING	METEORLOGICAL
FOR WAYPOINT #1		CONTROL TRANSITION	ALTITUDE	
		LAUNCHER PERFORMANCE		
		INITIAL RATE OF CLIMB		
WAYPOINT GUIDANCE	AUTO	INITIAL W/P GUIDANCE	CLIMB TO ≥ 600 M AGL	TLM
		W/P #1 ACQ	2 KM FROM GCS	GCS PLOT
		W/P #2 ACQ	2 KM FROM #1	FPS-16 RADAR
AIR VEHICLE	MAN. A/P	90, 110, 130, & 150 KM IAS	V AS STATED	TLM
PERFORMANCE		STR AND LEVEL	600M AGL	600 M AGL AIR TEMP
		ENGINE RPM	RACETRACK WITH	GCS VIDEO
		THROTTLE SETTING	STR. LEG ≥ 2 KM	FPS-16 RADAR
		3°/SEC TURNS		
		90° AND 180°		
		6°/SEC TURNS		
		90° AND 180°		

TABLE A-4. (CONT)

FLT PHASE	MODE	OBJECTIVES	FLT PROFILE	DATA REQ.
AUTOMATIC	AUTO	WAYPOINT 91 (81) ACQ	MIN 4 APPROACHES	TLM
RETIREVAL		CURSOR ACQ		H.S. PHOTO
APPROACH		GRD. CAMERA LOCATION		GCS VIDEO
		4^{o} DESCENT RATE		METEORLOGICAL
		WAVE OFF (400M RANGE)		
RETRIEVAL	R/C	HOOK ENGAGEMENT		TLM
		NET RETRIEVAL		H.S. PHOTO
				METEORLOGICAL
GENERAL		SAME AS FLT #015		

TABLE A-5. AQUILA PHASE A FLIGHT 017

FLT PHASE	MODE	OBJECTIVES	FLT PROFILE	DATA REQ.
LAUNCH, CLIMB AND INITIAL WAYPOINT WAYPOINT ACQ.	AUTO	AUTOMATIC LAUNCH AUTOMATIC CLIMBOUT INITIAL WAYPOINT ACQ	CLIMB TO 600M AGL $\leq$ 4 KM FROM GCS	TLM H.S. PHOTO METEOROLOGICAL FPS-16 RADAR
AIR VEHICLE	MAN. A/P	90, 110, 130 & 150 K_M IAS RATE OF CLIMB RATE OF DESCENT	V AS STATED $\leq$ 6 KM FROM GCS CLIMB 400-800M AGL DESCENT 800-400M AGL STR AT 600 $\pm$ 50M AGL	TLM FPS-16 RADAR 600M AGL AIR TEMP
AUTOMATIC RETRIEVAL APPROACH	AUTO	SAME AS FLT#017 EXCP. WAVE OFF (200M RANGE)	MIN 4 APPROACHES (OPTIONAL AUTO RETRIEVAL)	TLM H.S. PHOTO GCS VIDEO METEORLOGICAL
RETRIEVAL	R/C	HOOK ENGAGEMENT NET RETRIEVAL	OPTIONAL	TLM H.S. PHOTO METEORLOGICAL
GENERAL		SAME AS FLT #015		

TABLE A-6. SYSTEM MISSION CAPABILITY VALIDATION

PROGRAM ELEMENT	FLIGHT 28	29	30	△ 31
SENSOR DYNAMIC RESPONSE	o			
ROAD TARGET DETECTION & RECOGNITION*		o		
FIELD TARGET DETECTION & RECOGNITION*			o	

NOTES:

△ CONTINGENCY FLIGHT

* ARMY OBSERVERS

TABLE A-7. ARMY SYSTEM VALIDATION

PROGRAM ELEMENT	FLIGHT 32	33	34	35	△ 36	37	38	39	△ 40
ARMY CREW TRAINING	o	o	o	o					
ARMY FAMIL. FLIGHT						o			
ARMY ROAD TARGET MISSION							o		
ARMY FIELD TARGET MISSION								o	

NOTE

△ CONTINGENCY FLIGHT

Appendix B

ENGINEERING MEMORANDUM*

TITLE: CORRECTION OF DEFICIENCIES LEADING TO THE LOSS OF THE AQUILA 004 AIRCRAFT (FLIGHT 11)

EM No.: 5580-20
WBS No:
DATE: 7 Jun 76

AUTHORS: Grover L. Alexander

APPROVAL:
ENGRG:
SYS. ENGRG: H. R. Allison

I. FLIGHT ANOMALIES

Analysis of flight data tapes reveals the following anomalies associated with flight 11 and the subsequent loss of aircraft 004.

1. Upon launch the payload protector deployed and locked.
2. During flight in the waypoint mode, data link dropouts prompted the Test Director to elect to abort that portion of the flight.
3. Upon initiation of the test of the approach control mode, the recovery hook assembly failed to deploy, although several attempts and maneuvers were made to effect deployment.

II. ANOMALY RESOLUTION

Analysis of the data has shown the following:

1. Inertial and shock loads can potentially cause the payload protector solenoid to release.
2. The data link dropouts occurred at an aircraft/tracking antenna geometry which places the tracking beam in a command receiver antenna null. This is confirmed by the fact that the downlink video was solid at the time of link loss indication.

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*Lockheed Missiles & Space Company, Inc., Tactical Systems Engineering

3. The latch (electronic) which precludes more than one firing of the recovery hook assembly and payload protector solenoids (to prevent inadvertent excessive voltage sag during low RPM approach) was already triggered at time of launch. This prevented the solenoid from being fired at recovery mode initiation. Analysis indicates that the 'occurrance' of the electronic circuit latching happened between the pulling of the umbilical cord and launch – a period of between fifteen to twenty minutes.

III. CORRECTIVE ACTIONS

The following corrective actions are proposed:

1. The solenoid installation will be modified to prevent payload protector drop due to launch accelerations and shock.
2. The recovery hook assembly sheath will be redesigned to remove metal parts to relieve the antenna nulls and resulting dropouts.
3. A procedure and/or software change will be accomplished to prevent launch with the solenoid latch circuit locked. In addition, an in-flight reset capability will be provided to permit circuit reset.

Appendix C

"B" MODEL CHANGE DATA

TABLE C-1. "B" CHANGES – AIRFRAME MECHANICAL

ITEM	CHANGE DESCRIPTION	DATE COMPLETE	PERFORMANCE STATUS
1	<u>SKEG PIN REDESIGN</u> REPLACE PRESSED PIN WITH BOLT & SLEEVES TO ALLOW REPAIR.	11-29-76	SATISFACTORY SINCE INSTALLED
2	<u>PAYLOAD PROTECTOR</u> ROUND OFF LEADING EDGES OF PAYLOAD PROTECTOR TO REDUCE CHANCES OF SNAGGING NET.	12-20-76	SATISFACTORY SINCE INSTALLED
3	<u>EXTERNAL TEST CONNECTOR</u> MOUNT TEST CONNECTOR IN WELL ON FUSELAGE SKIN TO PROVIDE EXTERNAL ACCESSIBILITY.	1-31-77	SATISFACTORY SINCE INSTALLED

TABLE C-1. (CONT)

ITEM	CHANGE DESCRIPTION	DATE COMPLETE	PERFORMANCE STATUS
4	<u>LASER SHIELD</u> CORRECT A FIT PROBLEM; FIELD FIX ENTAILS SECURING SHIELD TO RPV USING BUNGEE CORDS.	2-4-77	FIELD FIX ACCEPTABLE
5	<u>ACCELEROMETER BRACKET</u> ACCELEROMETER MOUNTING BRACKET REDESIGNED TO ACCOMMODATE NEW ACCELEROMETER SHAPE.	12-20-76	SATISFACTORY SINCE INSTALLED
6	<u>COMMAND RECEIVER MOUNTING</u> REVISE MOUNTING ATTACH METHOD TO TRANSFER PLATE NUTS FROM RPV BULKHEAD TO COMMAND RECEIVER FLANGE.	12-14-76	SATISFACTORY SINCE INSTALLED

TABLE C-1. (CONT.)

ITEM	CHANGE DESCRIPTION	DATE COMPLETE	PERFORMANCE STATUS
7	TRACKING BEACON INSTALLATION DOCUMENT FIELD INSTALLATION.	2-7-77	DOCUMENTATION ONLY
8	PARACHUTE SYSTEM DELETION DOCUMENTATION TO DELETE PARACHUTE INSTALLATION FROM RPVs 14 & UP	1-17-77	DOCUMENTATION ONLY
9	QUICK DISCONNECT (FUEL LINE) IMPROVE ROUTING OF FUEL LINE TO AVOID CHAFING & FUEL LOCK.	1-6-77	SATISFACTORY SINCE INSTALLED
10	BATTERY STENCIL SAFETY NOTED ON BATTERY.	4-18-77	
11	PAYLOAD MOUNTING & DOME DAMAGE	-	STUDY IS IN PROCESS; FIELD FIX TWX'D TO RANGE IS BEING EVALUATED. ALTERNATIVE IS MAJOR REDESIGN OF PAYLOAD MOUNTING.

TABLE C-2. AQUILA "B" CHANGE SUMMARY ENGINE/FUEL SYSTEM

ITEM	DESCRIPTION	PERFORMANCE	DATE COMPLETED
1. DUAL CARBURETOR LINKAGE/TUNING	SIDE-MOUNTED CARBURETORS; ROTATED SERVO POSITION; CABLE LINKAGE CONTROL AND CAM LINKAGE. PROVIDES EASIER ADJUSTMENT OF IDLE RPM; ALLOWS USE OF AUTOPILOT RPM LIMITER AT IDLE POWER; AND PROVIDES SERVO OVERDRIVE PROTECTION.	ENGINE POWER IS EQUAL TO EARLIER DUAL-CARBURETOR ENGINES. FUEL CONSUMPTION IS IMPROVED; FLIGHT USE FOR B CHANGE ENGINES HAS AVERAGED 4.2 LB/HOUR VERSUS 4.7 FOR PREVIOUS DUAL-CARBURETOR ENGINES FOR SIMILAR FLIGHT DURATIONS. ENGINE WEIGHT IS DECREASED BY 0.5 LB.	2-28-77
2. ENGINE PERFORMANCE/ ANALYSIS	FLIGHT AND GROUND TESTS TO DETERMINE THRUST VARIATIONS WITH A REVISED PROPELLER.	ALTHOUGH STATIC THRUST WAS INCREASED, THE FLIGHT TEST COMPARISONS SHOWED NO IMPROVEMENT IN CLIMB RATE.	4-22-77

TABLE C-2. (CONT)

ITEM	DESCRIPTION	PERFORMANCE	DATE COMPLETED
3. FUEL SUCTION LOCK	AN INTERNAL EXTENSION WITHIN THE FUEL BLADDER TO PREVENT CLOSURE OF THE OUTLET BY A COLLAPSING BLADDER	THERE HAVE BEEN NO DOCUMENTED CLOSURES OF THE FUEL OUTLET.	1-6-77
4. FUEL LOW INDICATOR	PROVIDED A DISCONNECT ELECTRICAL CONNECTOR TO EASE FUELING/DEFUELING OPERATION. SHIM WAS ADDED TO CHANGE INDICATION TO 3 RATHER THAN 2 LB. REMAINING.	ALLOWS EASIER FUELING AND READS AN INDICATION OF 3 LB FUEL REMAINING.	1-19-77
5. FUEL TANK STENCIL	ADDS FUELING INSTRUCTIONS TO FUEL BLADDER.	NO EVIDENCE OF INCORRECT FUEL MIXTURE.	4-1-77
6. FUEL LINE 90-DEG ELBOW	LOCATED BETWEEN THE FUEL TANK AND THE QUICK DISCONNECT; IT ELIMINATES A KINK IN THE FUEL LINE.	ENGINE NO LONGER SUBJECT TO POSSIBLE FUEL STARVATION DUE TO CLOSED FUEL LINE – NO OPERATIONAL PROBLEMS.	4-7-77

TABLE C-2. (CONT)

ITEM	DESCRIPTION	PERFORMANCE	DATE COMPLETED
7. CONNECTOR RELOCATION	CONNECTOR FOR ENGINE ELECTRICAL HARNESS WAS RELOCATED ON THE AFT BULKHEAD TO EASE ENGINE REMOVAL AND REPLACEMENT.	ENGINE REMOVAL AND REPLACEMENT IS DONE MORE RAPIDLY.	3-2-77
8. ENGINE ALIGNMENT	REPLACED FOUR SEPARATE ENGINE MOUNT BRACKETS WITH A SINGLE PLATE.	REQUIREMENT FOR SHIMMING TO ALIGN ENGINES HAS BEEN LARGELY ELIMINATED; ONLY TWO OF TEN RPVs HAVE REQUIRED SHIMS.	2-9-77
9. CARBURETOR AIR TEMPERATURE	ADDED AIR TEMPERATURE PROBE TO ENGINE COMPARTMENT TO MEASURE INLET TEMPERATURES.	MEASUREMENTS HAVE INDICATED A 20° TO 30°F TEMPERATURE INCREASE WITHIN THE AFT COMPARTMENT OVER AMBIENT CONDITIONS.	3-2-77

TABLE C-2. (CONT)

ITEM	DESCRIPTION	PERFORMANCE	DATE COMPLETED
	RECOMMENDED		
10. FUEL LINE CHANGE	BETWEEN THE QUICK-DISCONNECT AND THE ENGINE THE INSIDE DIAMETER IS CHANGED FROM 1/4 to 1/8 IN.	TESTS HAVE SHOWN ALMOST TOTAL ELIMINATION OF OUT-GASSING AT HIGH ALTITUDES AND LOW PRESSURES.	

TABLE C-3. RPV ELECTRICAL

- DESIGN IMPROVEMENT

  - TEST CONNECTOR MADE ACCESSIBLE THROUGH RPV SKIN

  - PROVIDE ACCESS TO UNUSED TELEMETRY CHANNELS VIA SPECIAL INSTRUMENTATION CONNECTOR IN HARNESS

  - PROVIDE PULL-AWAY DESIGN TO UMBILICAL DISCONNECT

  - PROVIDE POWER DISCONNECT FOR RADAR BEACON

  - ADD CARBURATOR AIR TEMPERATURE TRANSDUCER

  - ADD PAYLOAD BUFFER ELECTRONICS TO PREVENT ERATIC PAYLOAD BEHAVIOR DURING LINK LOSS

- DESIGN EVOLUTION

  - DELETE HOOK RELATED WIRING

  - REVISE HARNESS TO INCORPORATE CHANGES PATCHED INTO PREVIOUS HARNESS DESIGN

- RELIABILITY

  - REPLACE ACCELEROMETER WITH IMPROVED DESIGN. EXISTING UNIT DEGRADED UNDER VIBRATION.

  - REPLACE SERVO MOTOR IN SERVO ACTUATOR WITH HIGHER QUALITY MOTOR.

TABLE C-4. FLIGHT CONTROL ELECTRONICS

- DESIGN IMPROVEMENT
  - ADD DEAD RECKONING INTEGRATOR CLAMP AND GCS TRIM CAPABILITY
  - REVISE ACCELEROMETER INTERFACE TO ACCOMODATE HIGHER QUALITY ACCELEROMETER
  - TLM RECHANNELIZATION - INCREASE STATUS DATA CHANNELS BY SUB-COMMUTATING SLOWER DATA
  - REVISE DESIGN TO PREVENT DEPLOYMENT OF PAYLOAD PROTECTOR WHEN RPV POWER IS APPLIED
  - ADD FILTERS TO RATE GYRO OUTPUT TO ELIMINATE ELEVON SERVO FLUTTER
  - INCREASE DYNAMIC RANGE OF PHUGOID DAMPER TO PREVENT FLIGHT INSTABILITY
  - REVISE DESIGN TO PROVIDE RAMP INSTEAD OF STEP TO THROTTLE SERVO DURING LINK LOSS AND ABORT
  - REVISE APPROACH ABORT AND LINK LOSS TO ELIMINATE POSSIBILITY OF STALL AND FOR FASTER CLIMB RESPONSE
  - REVISE VERTICAL GYRO CAGING TO OCCUR SIMULTANEOUS WITH PAYLOAD CAGING
  - REVISE SCALE FACTOR OF VERTICAL GYRO TLM DATA
- RELIABILITY CHANGES
  - ADD POWER TURN ON SURGE PROTECTION TO INTEGRATORS
  - ADD INPUT PROTECTION TO MULTIPLIERS
  - ADD INPUT PROTECTION TO CMOS DEVICES (WHERE POSSIBLE)
- DESIGN EVOLUTION
  - UPDATE PRINTED CIRCUITS TO INCORPORATE DESIGN CHANGES
  - DELETE OBSOLETE HOOK DEPLOYMENT CIRCUITRY

TABLE C-5. RF LINK "B" CHANGES

- RF LINK TEST NETWORK
  - ANTENNA COUPLERS
  - SWITCHABLE ATTENUATORS
- ANTENNA WIND PROTECTION
- TRACKING ANTENNA SCAN CONVERTER MODIFICATION
- INCREASE COMMAND LINK SENSITIVITY
  - DIPLEXED WITH DOWNLINK DISH FEED
  - RELOCATED RPV RECEIVER ANTENNA TO FAVORABLE POSITION
- INCREASE TLM/VIDEO LINK SENSITIVITY
  - ADDED FOUR HELIX ARRAY FOR LOW GAIN
  - ADDED PREAMPS
  - RECONFIGURED RF SYSTEM TO IMPROVE S/N
- IMPROVE TRACKING
  - INCREASED LOW GAIN SERVO LOOP GAIN
  - MODIFY ANTENNA CONTROL UNIT
    - ADD NULL GATE
    - STABILIZE BIAS CIRCUIT
    - BALANCE DEMODULATOR
- MINOR LOBE LOCKING
  - LAUNCH IN LOW GAIN
  - ANTENNA CONTROL UNIT MODIFICATION

TABLE C-6. SUMMARY OF THE GCS ANTENNA CHANGES

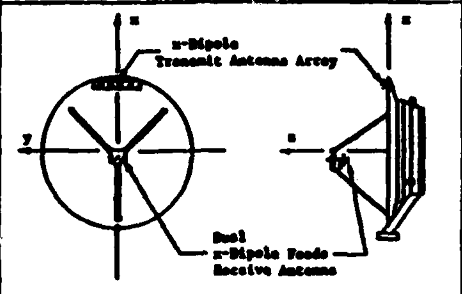
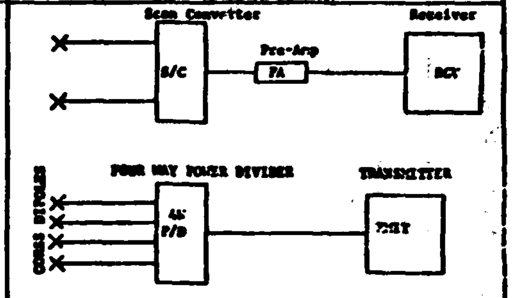
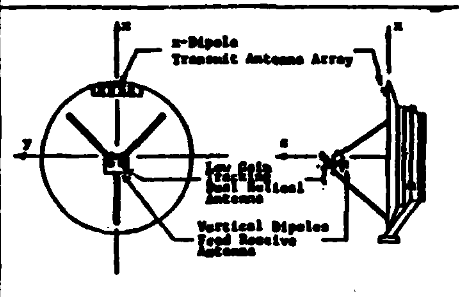
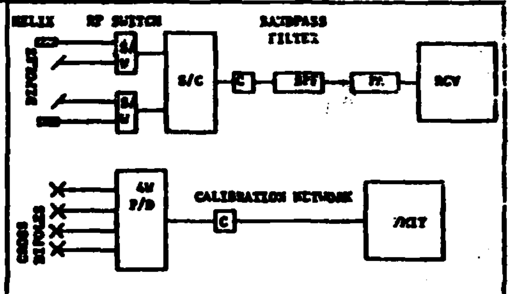
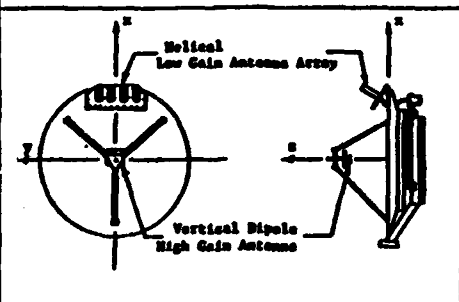
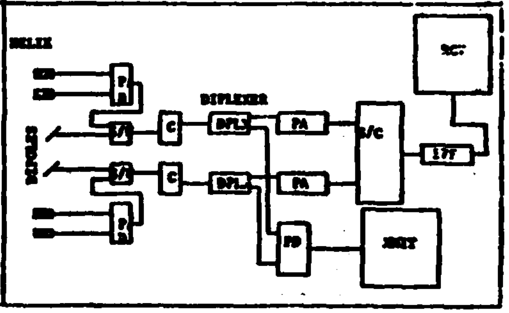
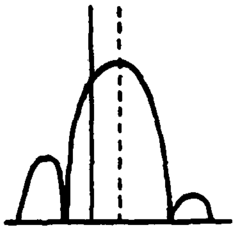
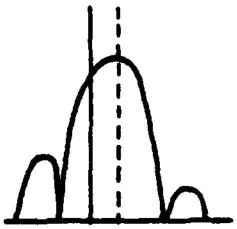
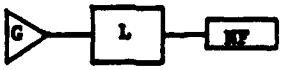
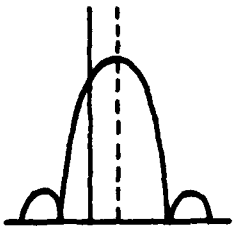
SYSTEM	ANTENNA SYSTEM DESCRIPTION	ANTENNA CONFIGURATION	RF BLOCK DIAGRAM
ORIGINAL	• TRACKING ANTENNA - 2' Parabolic Dish with Offset Cross Dipole Array - Scan Converter (S/C) and Preamp • TRANSMIT ANTENNA - Four Cross Dipole Array tilted 15° Up - Four Way Power Divider		
A MOD	• TRACKING ANTENNA HIGH GAIN* - 2' Parabolic Dish with Offset Vertical Dipole Array LOW GAIN* - Dual Helical Array Tilted 30° Up *Each is common to calibration network, bandpass filter, and scan converter through RF switches. • TRANSMIT ANTENNA - Four Cross Dipole Array Tilted 15° Up - Four Way Power Divider and a Calibration Network		
B MOD	• TRACKING AND TRANSMIT ANTENNA HIGH GAIN* - 2' Parabolic Dish With Focal Fed Vertical Dipole Array LOW GAIN* - Four Helical Array Tilted 30° Up. *Each is common to calibration network, diplexer, and 2-two way power divider through RF switches. • The Transmit Section contains additional two way power divider. • The Tracking Section contains additional preamp, scan converter, and bandpass filter.		

TABLE C-7. EVALUATION OF ANTENNA MODIFICATION

ANTENNA PERFORMANCE	RF COMPONENTS	FIGURE OF MERIT $M = G - L - NF$
1. ORIGINAL 	$L = 3.04$ db  $G = 23$ db $NF = 5.5$ db	$M_1 = 14.46$ db
2. "A" MODIFICATION 	$L = 3.75$ db  $G = 26$ dbi $NF = 5.5$ db	$M_2 = 16.74$ db $\frac{M_2'}{M_1} = +2.28$ db
3. "B" MODIFICATION 	$L = 1.89$ db  $G = 26$ dbi $NF = 2.7$ db	$M_3 = 21.41$ db $\frac{M_3'}{M_1'} = +6.95$ db

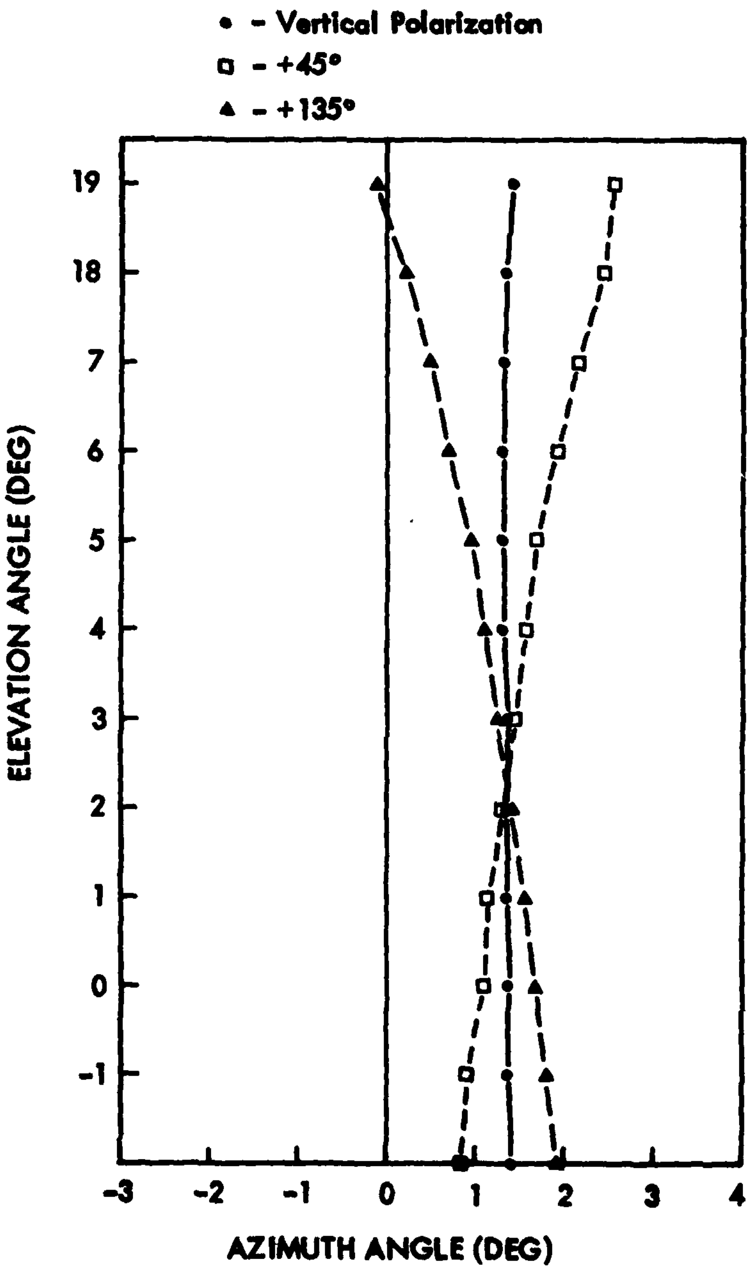


Figure C-1. Aquila GCS "B" Change High-Gain Tracking Antenna S/N 003, Parabolic Dish With Dual Dipole Array Feed

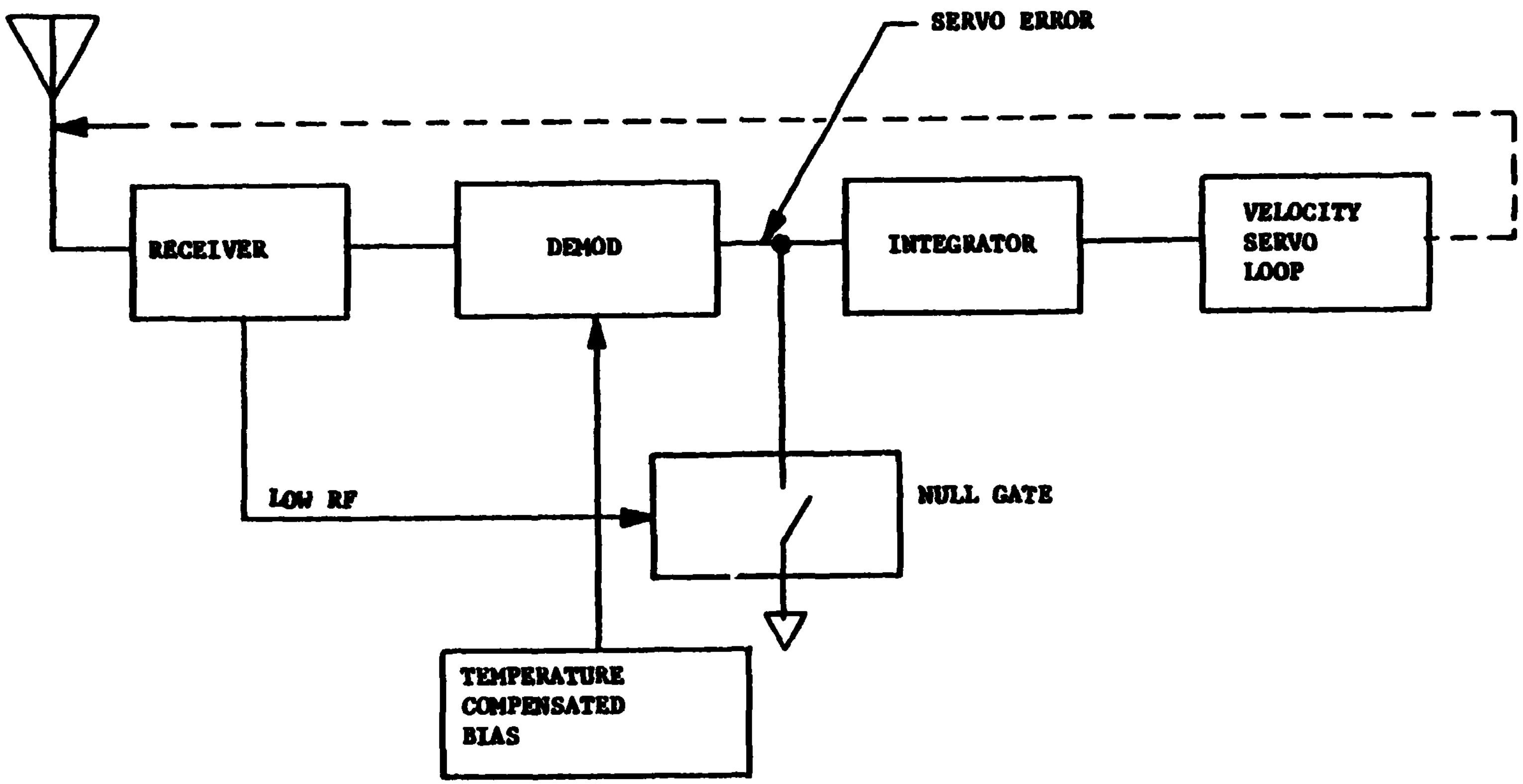


Figure C-2. Antenna Control Unit Modification

TABLE C-8. GCS CONSOLE "B" CHANGES

- MODIFICATIONS
  - HOOK - PARACHUTE DELETION
  - IN FLIGHT DIAGNOSTIC PANEL
  - PHASE IV/V SENSOR COMPATIBILITY
  - CPU MOD FOR DIAGNOSTICS
  - DEAD RECKONING TONE
  - CAMERA FRMAE COUNTER
  - COMPUTER SWITCH SHIELD
  - SECOND TOPAZ UNIT INCORPORATION
  - WAYPOINT DISPLAY NOISE
  - FAIL SAFE LAUNCH VELOCITY
  - PAYLOAD GYRO ERECTION COMMAND
  - AUXILIARY EQUIPMENT RACK CONFIGURATION
  - TRAINER SIMULATOR INSTALLATION
  - LASER ENABLE SWITCH
  - INTERCOM BUFFER AND WIRING
  - SENSOR OPERATIONS PANEL
  - GSS CONNECTOR PROTECTION
  - GSS HEADSET STORAGE
- ATP CHANGES
  - INCORPORATE "B" CHANGES
  - INCORPORATE ALTITUDE AND IAS COMMAND AND STATUS METER CALIBRATION
  - INCORPORATE IN FLIGHT DIAGNOSTIC PANEL
  - INCORPORATE ANTENNA CONTROL UNIT MODIFICATIONS

TABLE C-9. AQUILA "B" SOFTWARE CHANGE SUMMARY

1. DEAD RECKONING
   - CORRECTED MAGNETOMETER SIGNAL POLARITY
   - ADDED MAGNETIC DEVIATION CORRECTION
   - HARDWARE CHANGE REQUIRED FOR DR TERMINATION

2. RPV ROLL STABILIZATION
   - ADDITION OF LEAD-LAG TO RATE TERM IN HEADING RATE COMMANDS ($\pm$ 12°/SEC TO $\pm$ 6°/SEC)
   - INCREASE UPDATE RATE TO 2 SAMPLES PER SECOND
   - ADD $\ddot{H}$ LIMITS TO 0.4 DEG/SEC^2
   - INCREASE $\ddot{H}$ LIMITS TO 1.2 DEG/SEC^2

3. DECOMMUTATION OF RPV MULTIPLEX CHANNELS
   - RESTORE SENSOR DATA LINK CHANNEL FUNCTIONS AND RETAIN RPV STATUS DATA

4. SENSOR DEPRESSION ANGLE DISPLAY CALIBRATION
   - 15 DEGREE ERROR REMOVED

5. VERTICAL GYRO ERECTION CUT OFF CONTROL

6. TARGET LOCATION COMPUTATIONS
   - MAGNETIC HEADING CORRECTIONS
   - ARTILLERY ADJUSTMENT CORRECTIONS
   - COMPUTED AVERAGE VALUES FOR DISPLAY
   - INCREASE GYRO OUTPUT VALUE RESOLUTION
   - CORRECTED TARGET LOCATION EQUATION SIGNS.

TABLE C-10. AQUILA SOFTWARE CHANGE RECOMMENDATION SUMMARY

7. RATE FILTER INITIALIZATION

- INITIALIZE RATE FILTER TO PERMIT LOITER OVER TARGET AND 1800 M OFFSET FROM TARGET.

8. PHASE II CAMERA DATA INITIALIZATION

- RESET FRAME COUNT AND MISSION TIME

TABLE C-11. RETRIEVAL SYSTEM

ITEM	PERFORMANCE	EST. COMPLETION	REMARKS
VERTICAL BARRIER SYSTEM DOCUMENTATION	58 KNOTS MAX.; 6 G MAX. IN 3 AXES	30 JUNE 1977	LMSC PERFORMANCE REPORT DRAFT COMPLETED; AAE TO SUPPLY ORIGINAL DRAWINGS
ENERGY ABSORBER	20- TO 35-KNOT GUSTS 4,000 FT/95 F DAY	15 JULY 1977	150-LB RELEASE REQUIRED; NEW HOLDBACK PINS REQUIRED
VERTICAL BARRIER SYSTEM	SYSTEM NO. 1 OPERATIONAL	15 JULY 1977	IN USE SINCE SEP 1976
	SYSTEM NO. 2 COMPLETED	15 JULY 1977	DELIVERED TO FT. HUACHUCA JUN 1977

TABLE C-11. (CONT)

ITEM	PERFORMANCE	EST. COMPLETION	REMARKS
RECOVERY CAMERA			
– LEVEL BUBBLE	McMASTER-CARR LEVEL	9 NOV 1976	SATISFACTORY
– UV FILTER	4,000-100 Å	TBD	PRELIMINARY DESIGN COMPLETE

TABLE C-12. LAUNCHER SYSTEM

ITEM	PERFORMANCE	DATE COMPLETED	REMARKS
STARTER ASSEMBLY			
• RETRACT LATCH	POSITIVE RETRACT	1 MAY 1977	COMPLETED
• HEAD GUARD		1 JUNE 1977	COMPLETED
GROUND COOLING		15 MAY 1977	SATISFACTORY OPERATIONS
• RPV ADAPTER	530 CFM		
• SUPPORT & PAD	1 IN. – H_2O		
REMOTE DISCONNECT		15 MAY 1977	SATISFACTORY OPERATIONS
• UMBILICAL LATCH	20-LB DISCONNECT		
• LANYARD & PADEYES	50- TO 70-LB LANYARD		
ACCUMULATOR DRYERS		17 JUNE 1977	DRY BETWEEN LAUNCH CYCLES
• DRYER ASSEMBLY	500 PSIG MAXIMUM		
• TIMER & CONTROL	40 W		

TABLE C-12. (CONT)

ITEM	PERFORMANCE	DATE COMPLETED	REMARKS
VELOCITY COUNTER – COUNTER DESIGN, NOISE LIMITING	20 μSEC COUNTER 30 KNOTS & UP RESOLUTION	17 JUNE 1977	SATISFACTORY OPERATIONS AT CONTROL BOX
SHUTTLE DESIGN – LIGHT WEIGHT, IMPROVED SHOCKS, IMPROVED CABLES	85 LB, 55-KNOT QUAL., 250 LAUNCHES	17 JUNE 1977	SATISFACTORY OPERATIONS (25 LAUNCHES TO DATE – RPV OR EQUIVALENT)
LAUNCHER SYSTEMS	SYSTEM NO. 1 OPERATIONAL	13 JUNE 1977	SER. NO. 9753
	SYSTEM NO. 2 OPERATIONAL	17 JUNE 1977	SER. NO. 10755

Appendix D

ENGINEERING MEMORANDUM*

TITLE: AQUILA FLIGHT PERFORMANCE

EM No: 5583-111
WBS No:
DATE: 4 Nov 77

AUTHORS: J. H. McVernon

APPROVAL: F. A. Velligan
ENGRG:
SYS. ENGGR: N. G. Tosch

I. INTRODUCTION

This memo presents Aquila Flight performance characteristics, as derived from the present Ft. Huachuca flights, for different weights and altitudes. In addition, comparison is made between the predicted and actual performance to understand better the differences between wind tunnel and flight test results.

II. DISCUSSION

The basic measure of vehicle performance, demonstrated rate of climb, is shown in Figure D-1 for different vehicles, altitudes, and weights. Correcting the altitude variable to a common level (2000 m) results in a variation with weight as shown in Figure D-2. The climb rate variation at about ±20 percent represents both the difference between vehicles and the difficulty of controlling and measuring flight conditions. In this group of four vehicles, No. 006 was the lowest performer.

*Lockheed Missiles & Space Company, Inc., Tactical Systems Engineering

Rate of climb and descent performance are given in Figures D-3 through D-10 based on test data and analysis to account for weight, altitude and speed.

It was recognized early in the flight test program that vehicle performance was less than predicted. This was attributed to error in the vehicle drag or thrust estimates. The best current estimates of the vehicle drag and thrust characteristics are given in a 1977 LMSC report.* In the reference, the lift-drag polar (Fig. 5-1) is based on wind tunnel test of a half-scale model with estimated allowance for the differences between the model and flight vehicle. The propeller thrust characteristics (Fig. 5-41) are from wind tunnel test of an actual Aquila propeller, without duct, on another RPV. Estimating flight performance, using these drag and thrust curves and the flight test propeller rpm, results in predicted performance greater than test results as shown in Figure D-11. It is not clear whether the thrust or drag is at fault. Arbitrarily reducing thrust 15 percent and adding 0.005 to the drag coefficient results in closer agreement. (Other more or less proportionate changes in the thrust and drag could also be used to match the test data.) The relative effect of these adjustments on thrust horsepower are shown in Figure D-12.

Airspeed-altitude flight envelopes were derived for different weights on the basis of the adjusted thrust and drag. The climb rates from minimum to maximum airspeeds are shown in Figures D-13, D-14, and D-15. Minimum airspeeds are based on elevon deflection limit (-20°) at maximum lift coefficient from the wind tunnel data, as shown in Figure D-16. No flight tests were done to explore low-speed characteristics. Flight test indicates that elevon deflections for low speed may be greater than indicated by wind tunnel test as shown in Figure D-17. If so, then the minimum flight speed at elevon deflection limit will be higher than presently estimated.

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*LMSC-L028081, Part 4, May 1977, <u>Aerodynamics</u>

Best climb speed is about 105 km/h TAS for the weights and altitudes investigated. This airspeed corresponds to 90 km/h IAS at 2000 m altitude, typical of Aquila flight operations at Ft. Huachuca. Maximum rate of climb is shown in Figure D-18. This curve, derived from the thrust and drag adjustments to fit vehicle 013 performance, has about 20 m/min better climb than the climb rate shown earlier in Figure D-3 which was based on a group of vehicles. The loss in climb rate with altitude increase or weight increase is the same in both cases, Figure D-18 and Figure D-3.

Maximum level flight speeds are given in the airspeed-altitude flight envelopes, Figure D-19 and D-20, as derived from the zero climb rate speeds of Figures D-13, D-14, and D-15. Again, these speeds are for the adjusted thrust and drag curves to fit one vehicle, and, if we can expect to see 20 m/min variation in climb rate between vehicles, then maximum speeds could be expected to vary 5 to 10 km/h TAS between vehicles, depending on weight and altitude.

Airspeed and density altitude curves, for performance analysis and flight operation, are given in Figure D-21 through D-24. The airspeed correction, true vs. indicated, given in Figure D-21 accounts for both altitude density effect and the airspeed sensor errors. These errors, for the pitot-static installation and pressure transducer, are also shown separately in Figure D-22 and D-23. Flight test airspeeds were corrected on the basis of these curves, assuming the differences between vehicles and the wind tunnel airspeed calibration data were small.

III. SUMMARY AND CONCLUSIONS

Flight performance characteristics have been established on the basis of flight test. Flight data, limited to Ft. Huachuca test conditions, have been expanded in scope to other altitudes, speeds, and weights by analytical means. Climb performance is based on a group of flight vehicle data, including lower performance

data. Most vehicles should equal or better the climb shown. Other performance characteristics, being based on fewer data points, may be in variance with some vehicles. The performance curves to be used are:

Performance Item	Figures
Max. rate of climb*	D-3, D-4
Rate of descent*	D-5 through D-10
Rate of climb vs. velocity**	D-13, D-14, D-15
Airspeed - altitude envelope**	D-19, D-20

Flight performance predicted on the basis of wind tunnel data is higher than flight results. We need to improve our analytical model of both the vehicle and propulsion characteristics for better prediction and analysis of vehicle performance.

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*Based on nominal flight test data.
**Based on high performance flight test 38, RPV-STD-013.

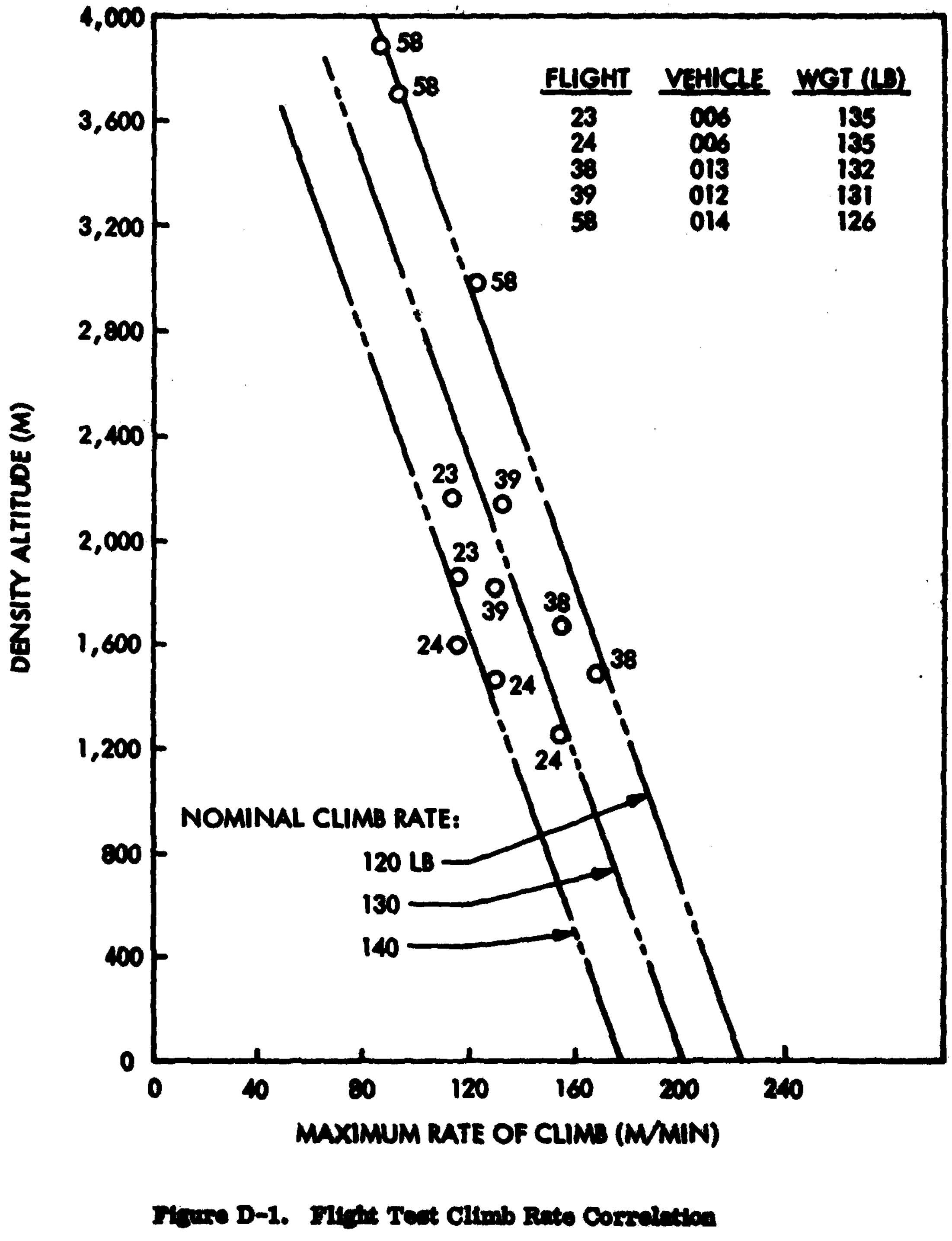


Figure D-1. Flight Test Climb Rate Correlation

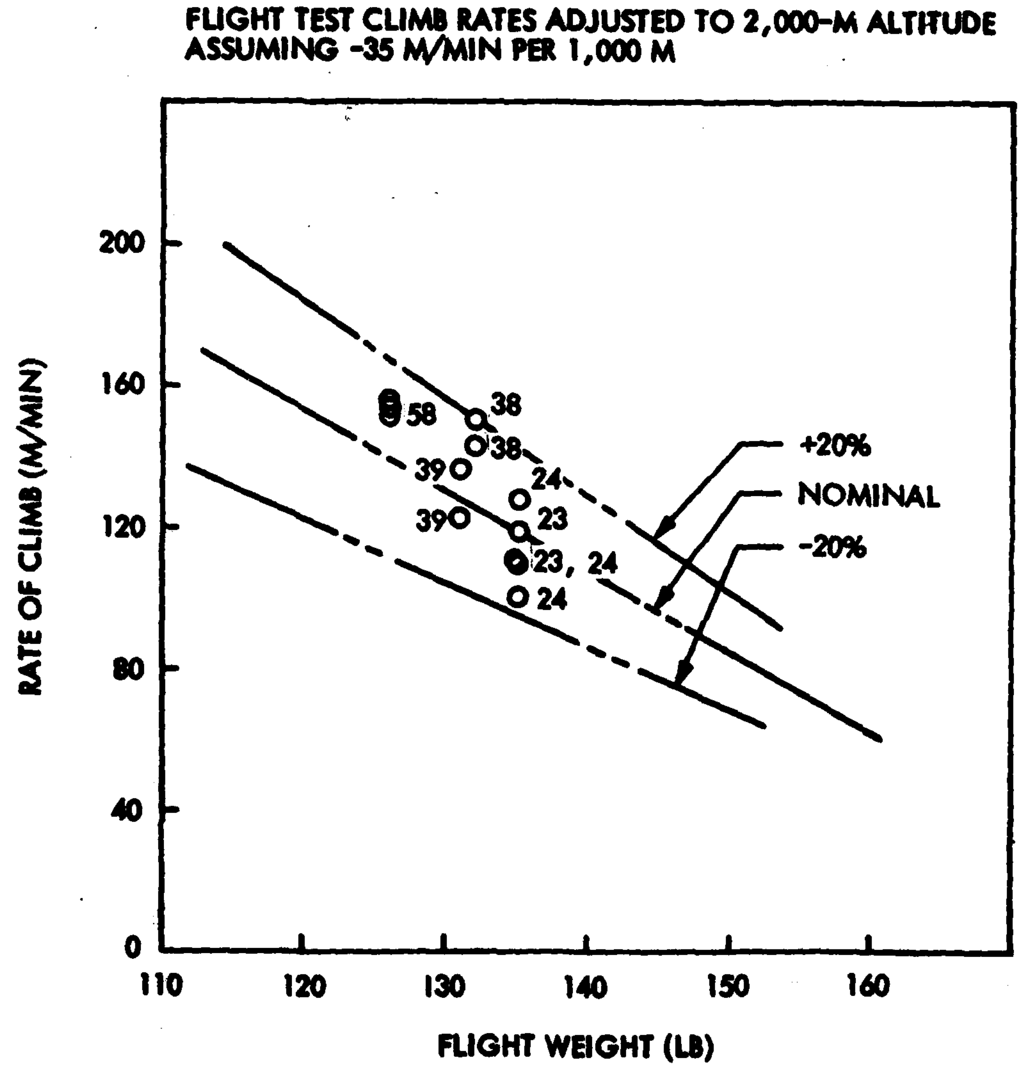


Figure D-2. Climb Rate Correlation at 2,000-m Density Altitude

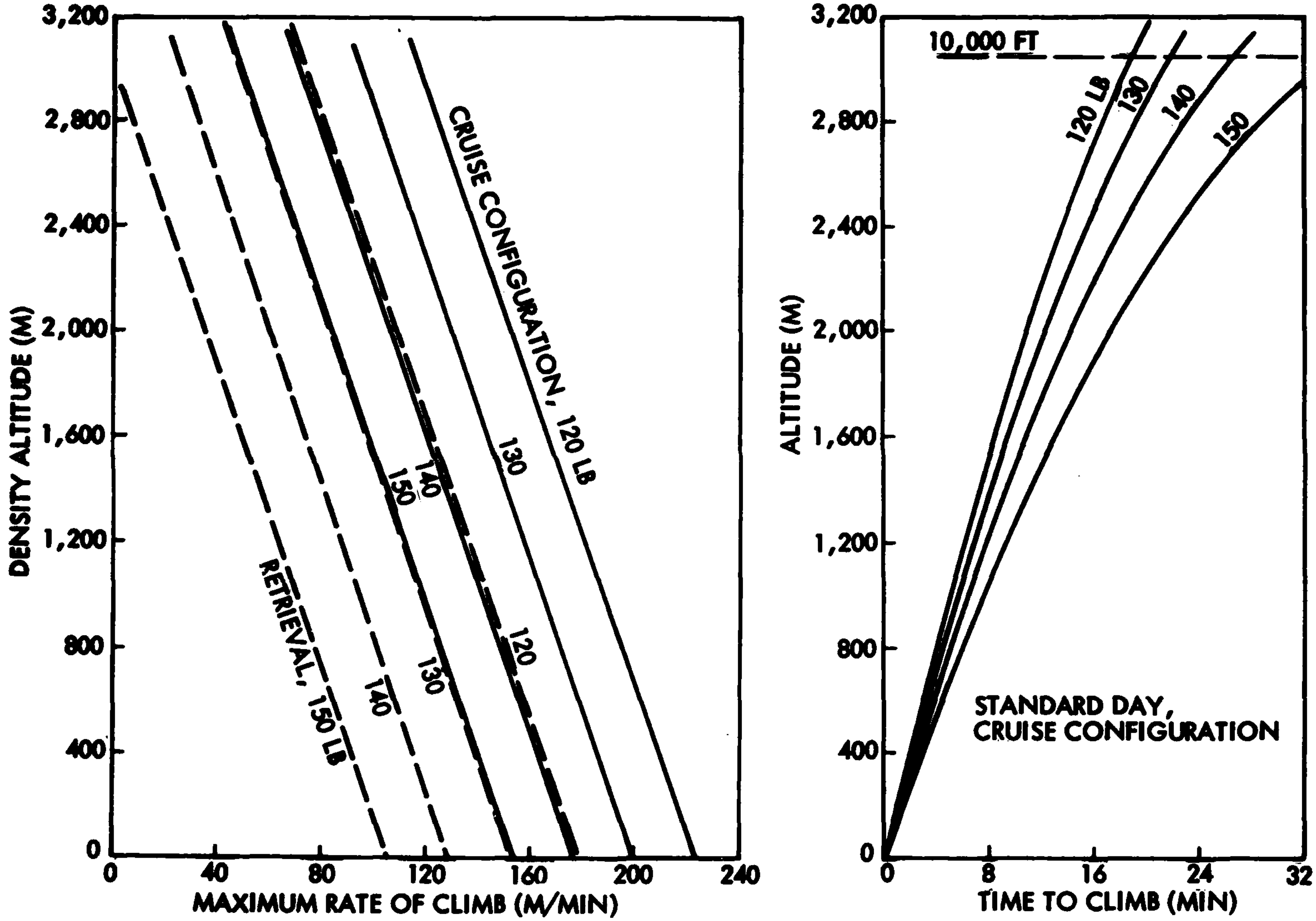


Figure D-3. Climb Performance, Metric Units

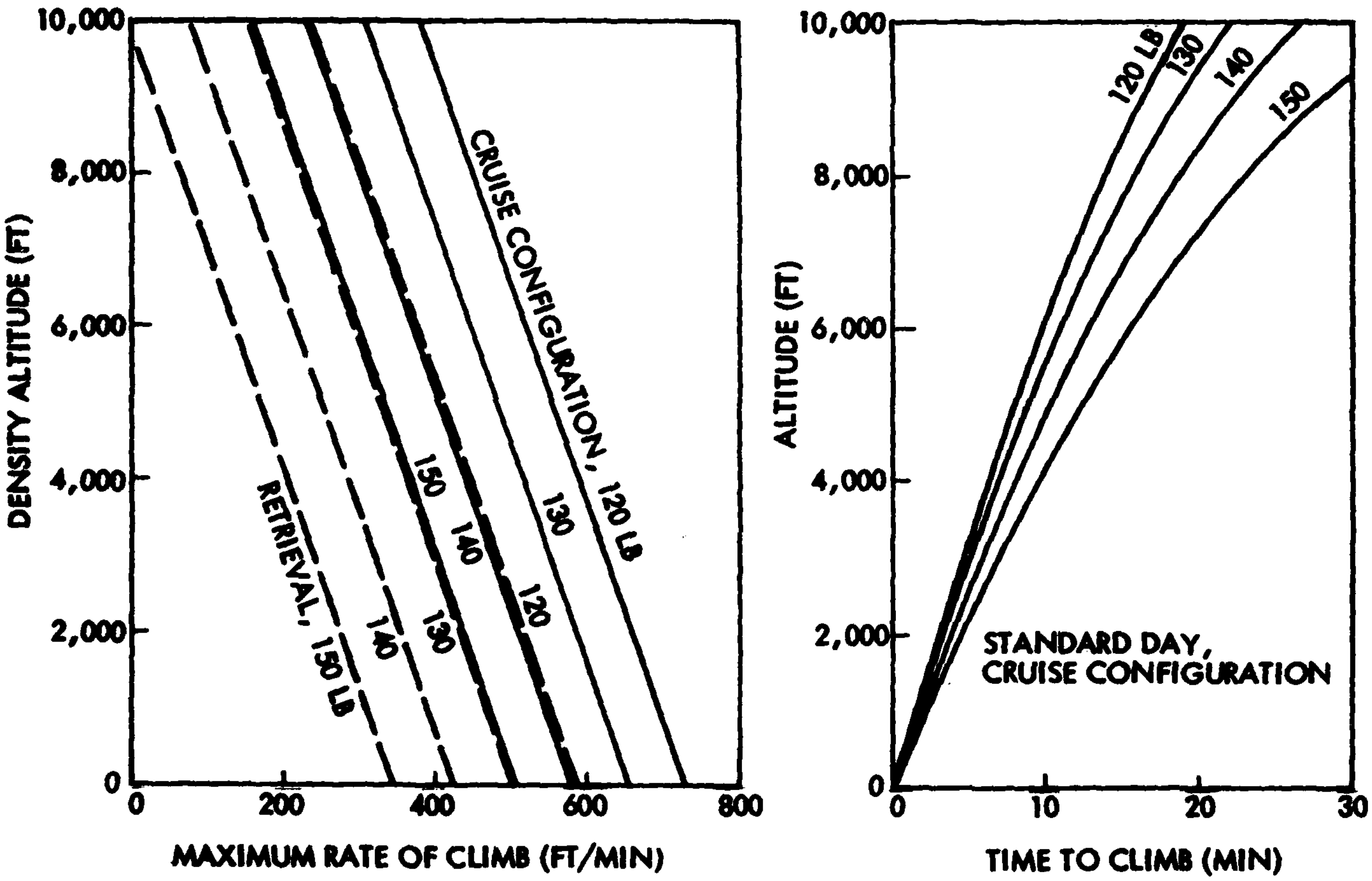
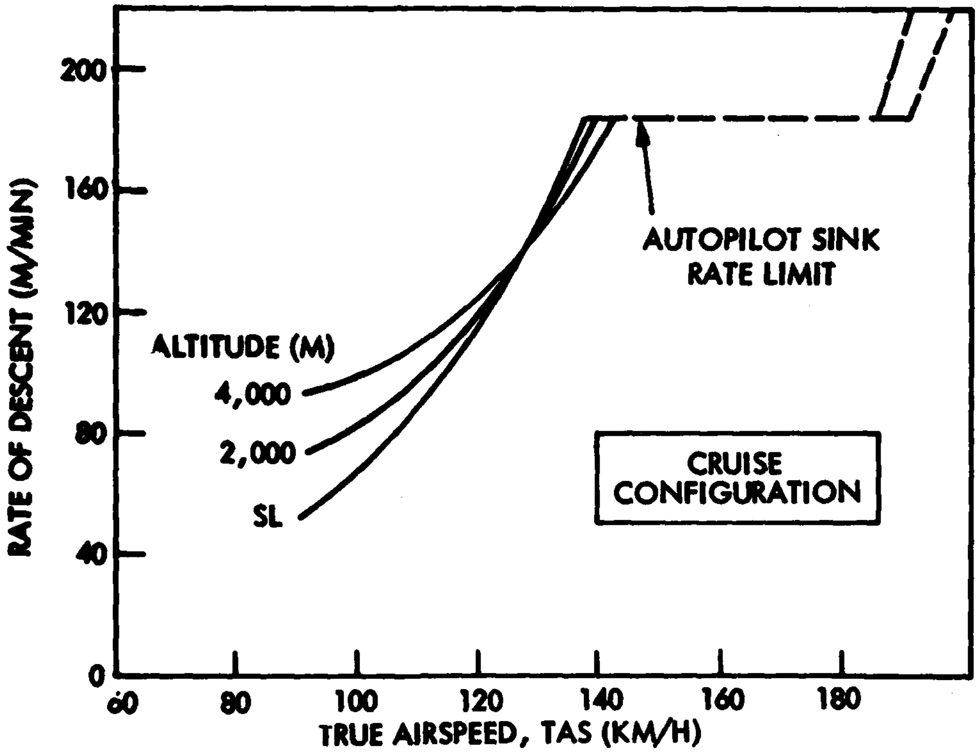


Figure D-4. Climb Performance, English Units



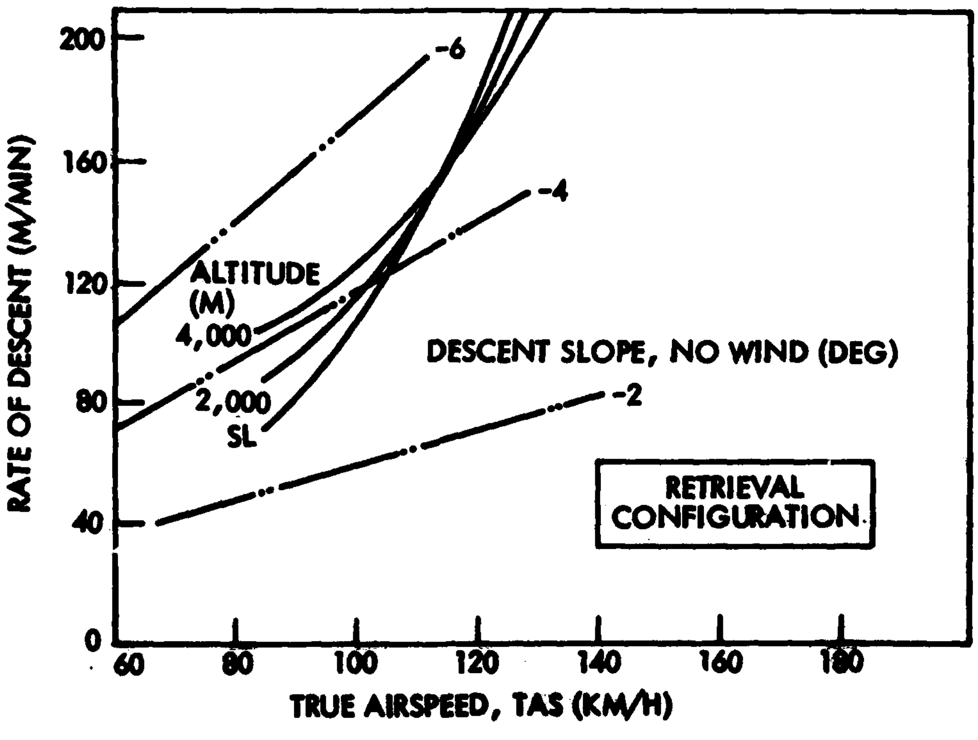


Figure D-5. Rate of Descent, 130 lb, TAS

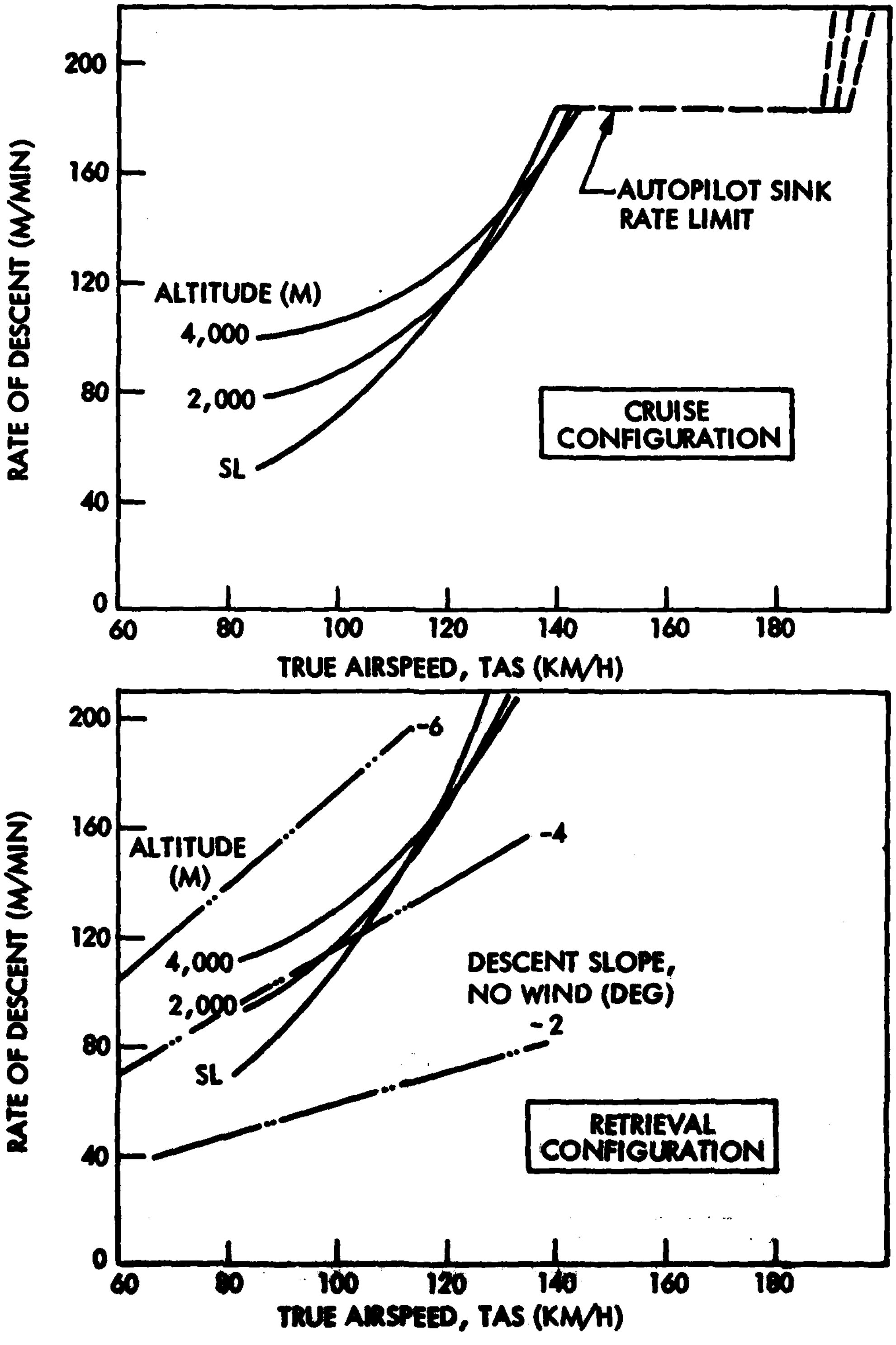
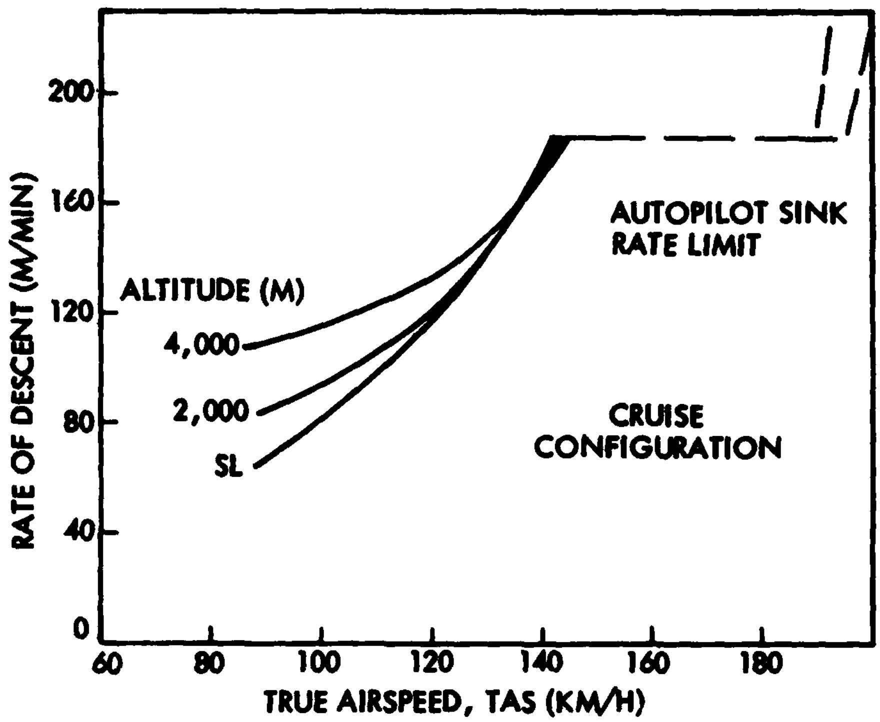


Figure D-6. Rate of Descent, 140 lb, TAS



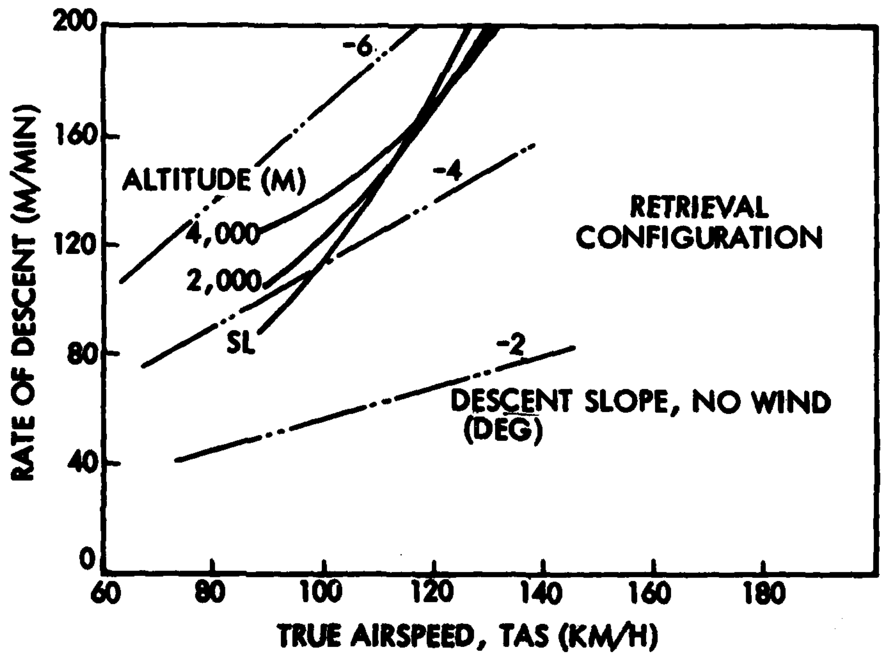


Figure D-7. Rate of Descent, 150 lb, TAS

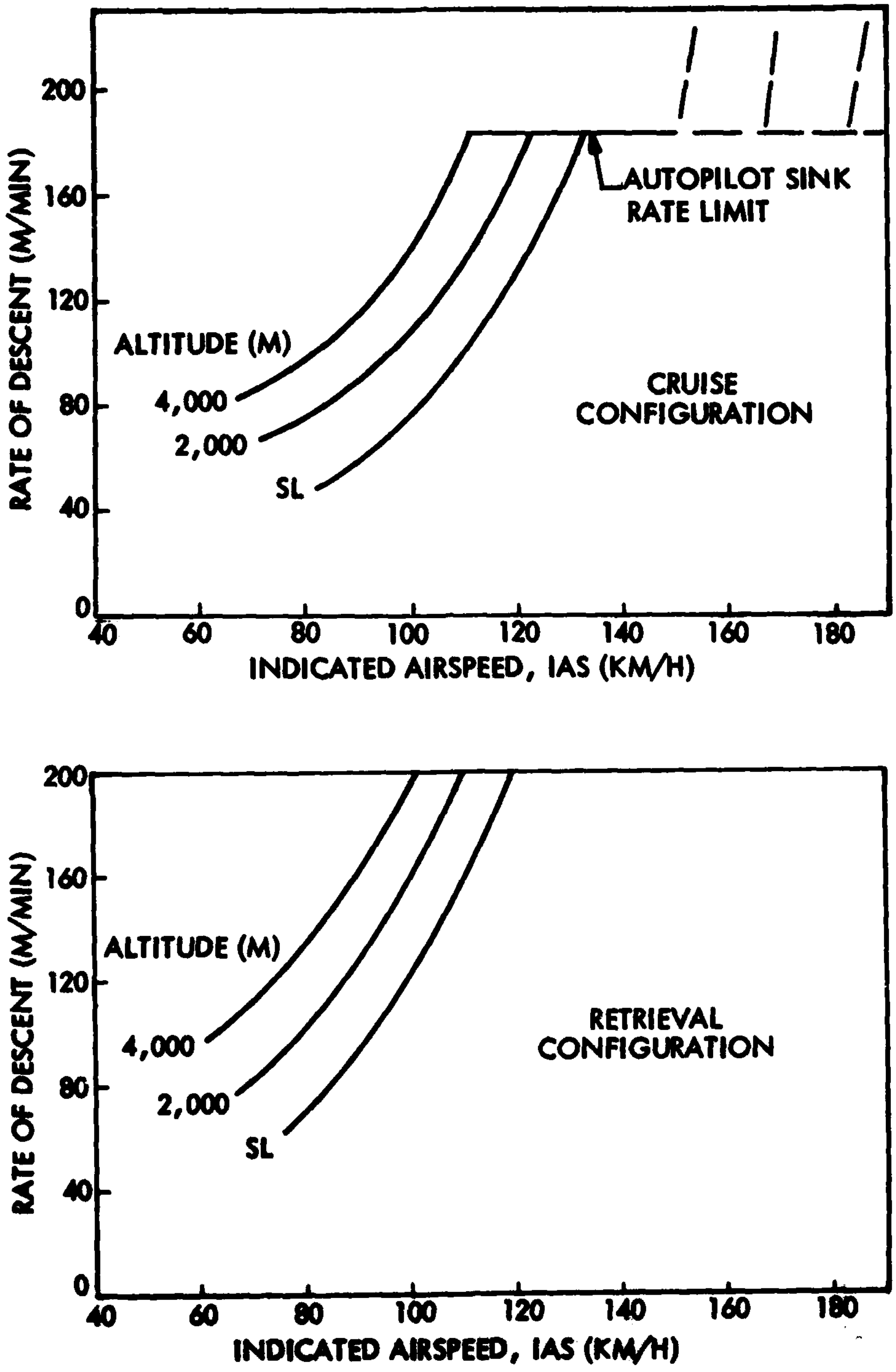


Figure D-8. Rate of Descent, 130 lb, IAS

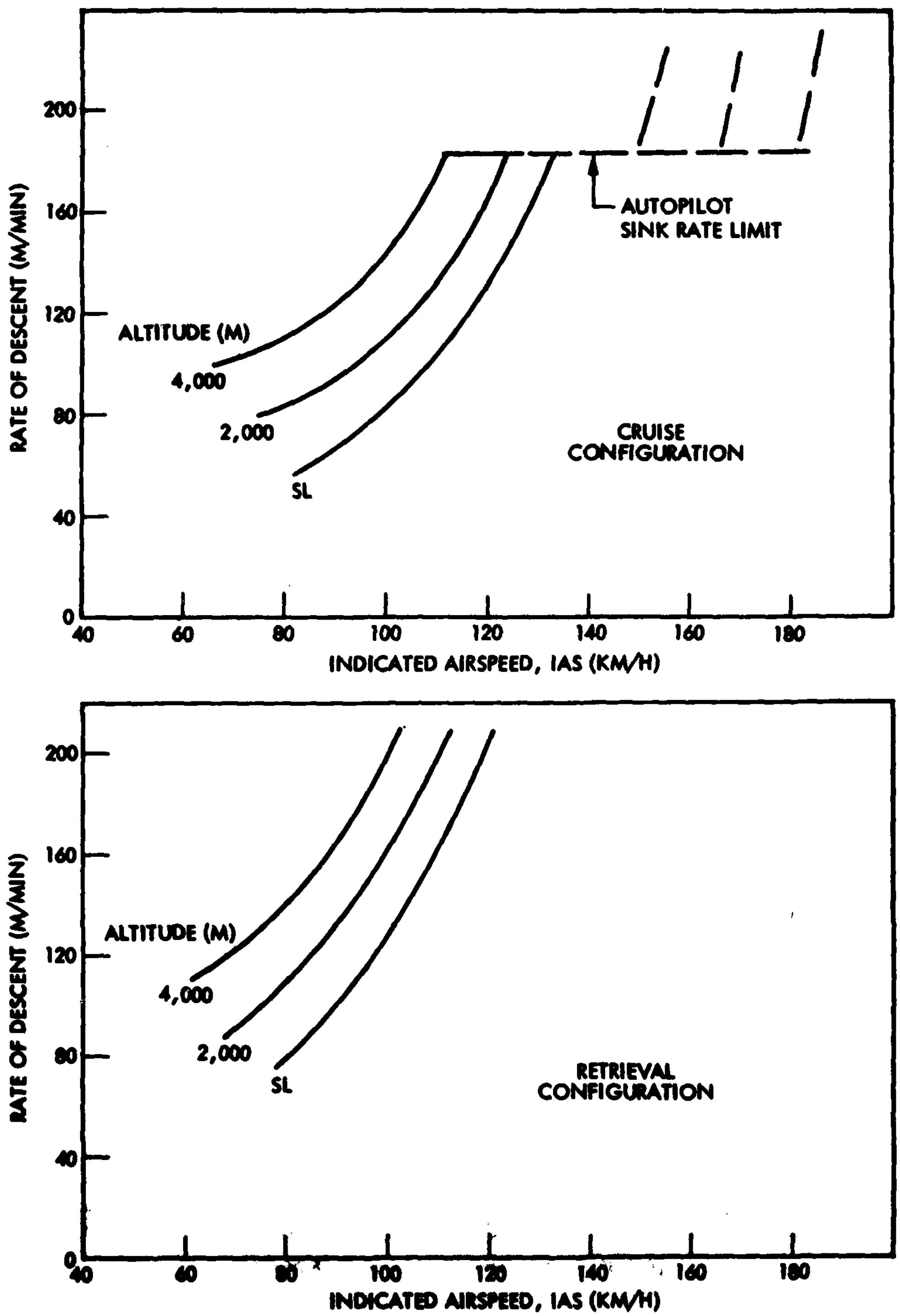


Figure D-9. Rate of Descent, 140 lb, IAS

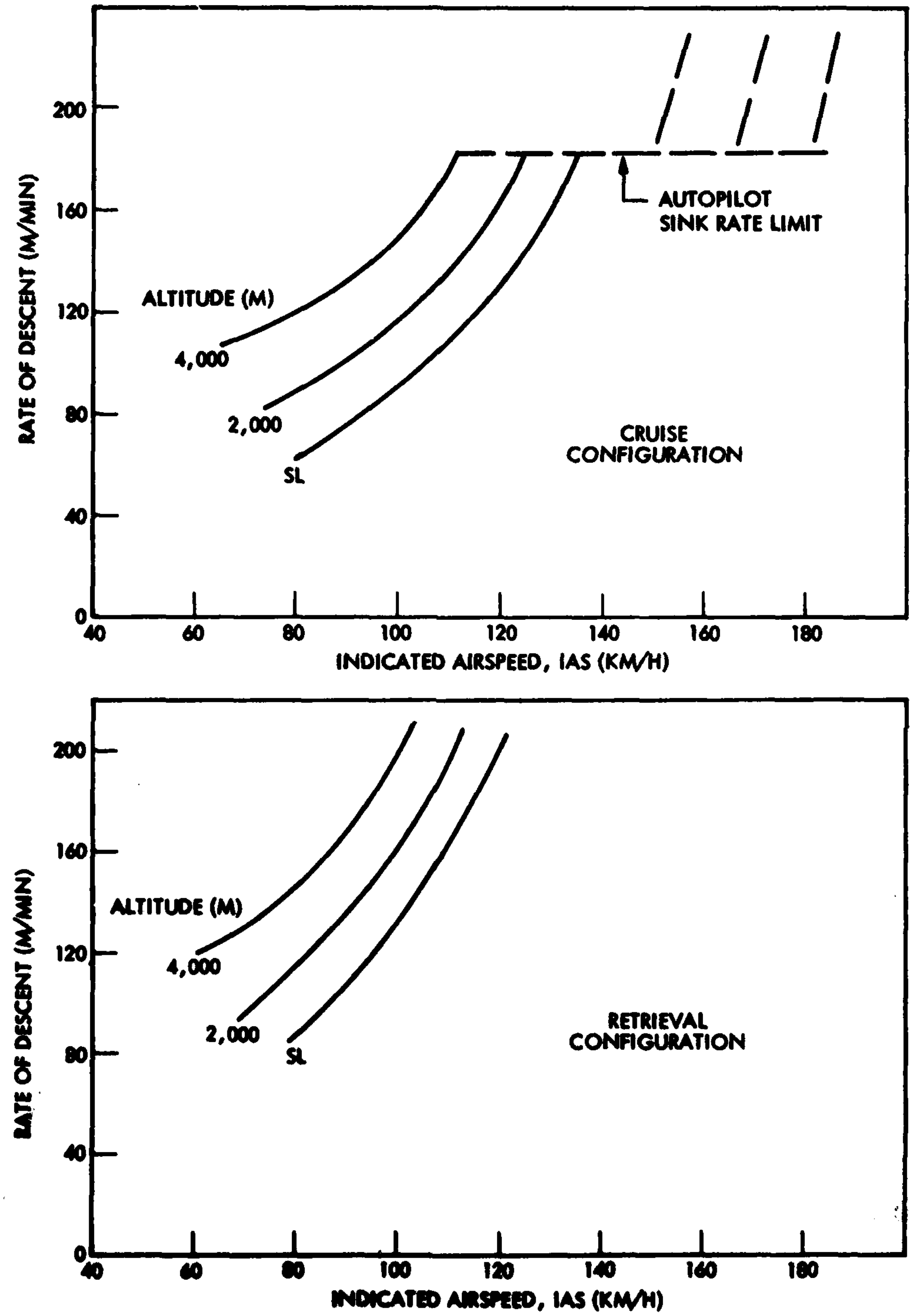


Figure D-10. Rate of Descent, 150 lb, IAS

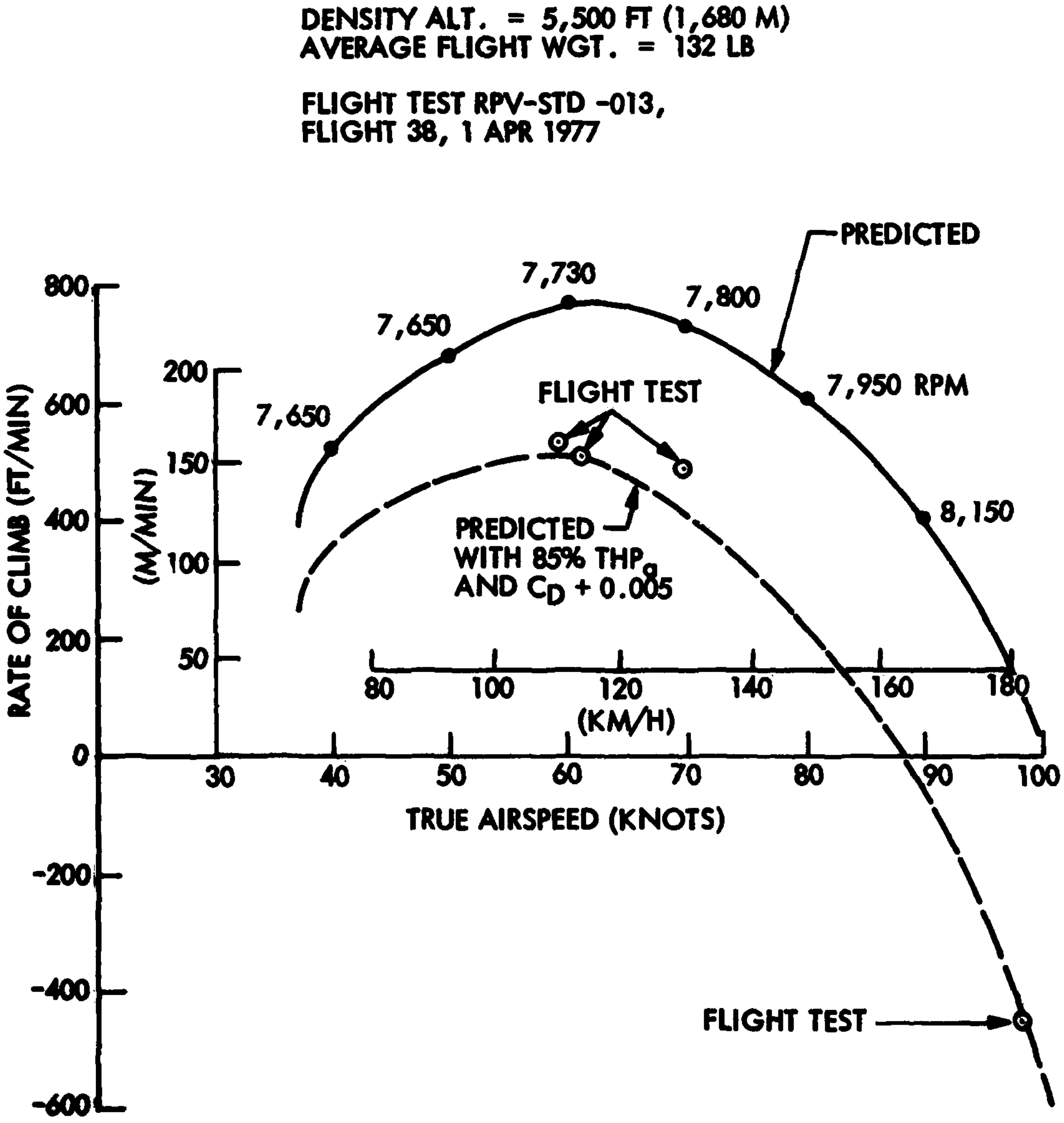


Figure D-11. Performance Correlation

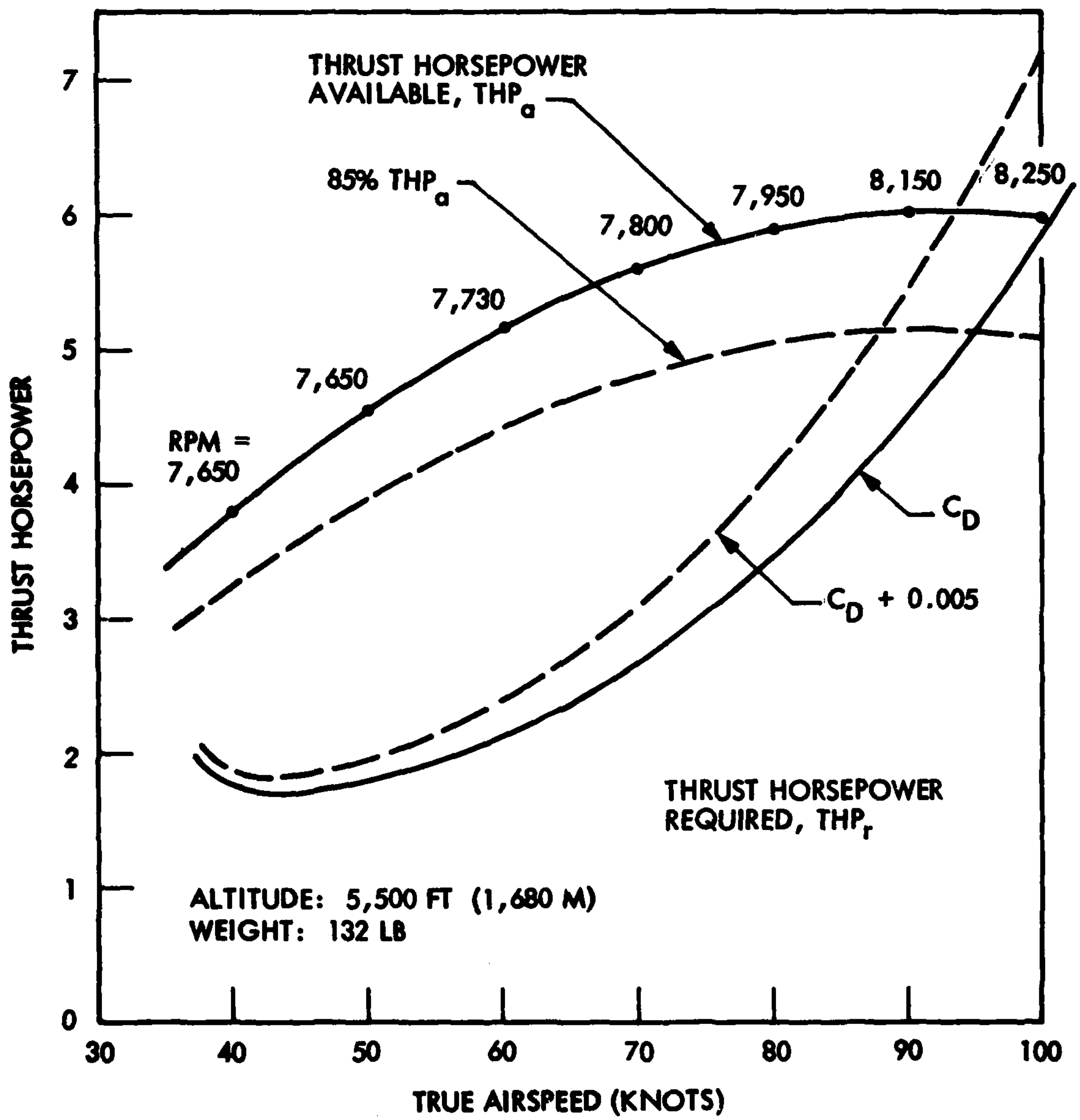


Figure D-12. Thrust Horsepower Adjustments

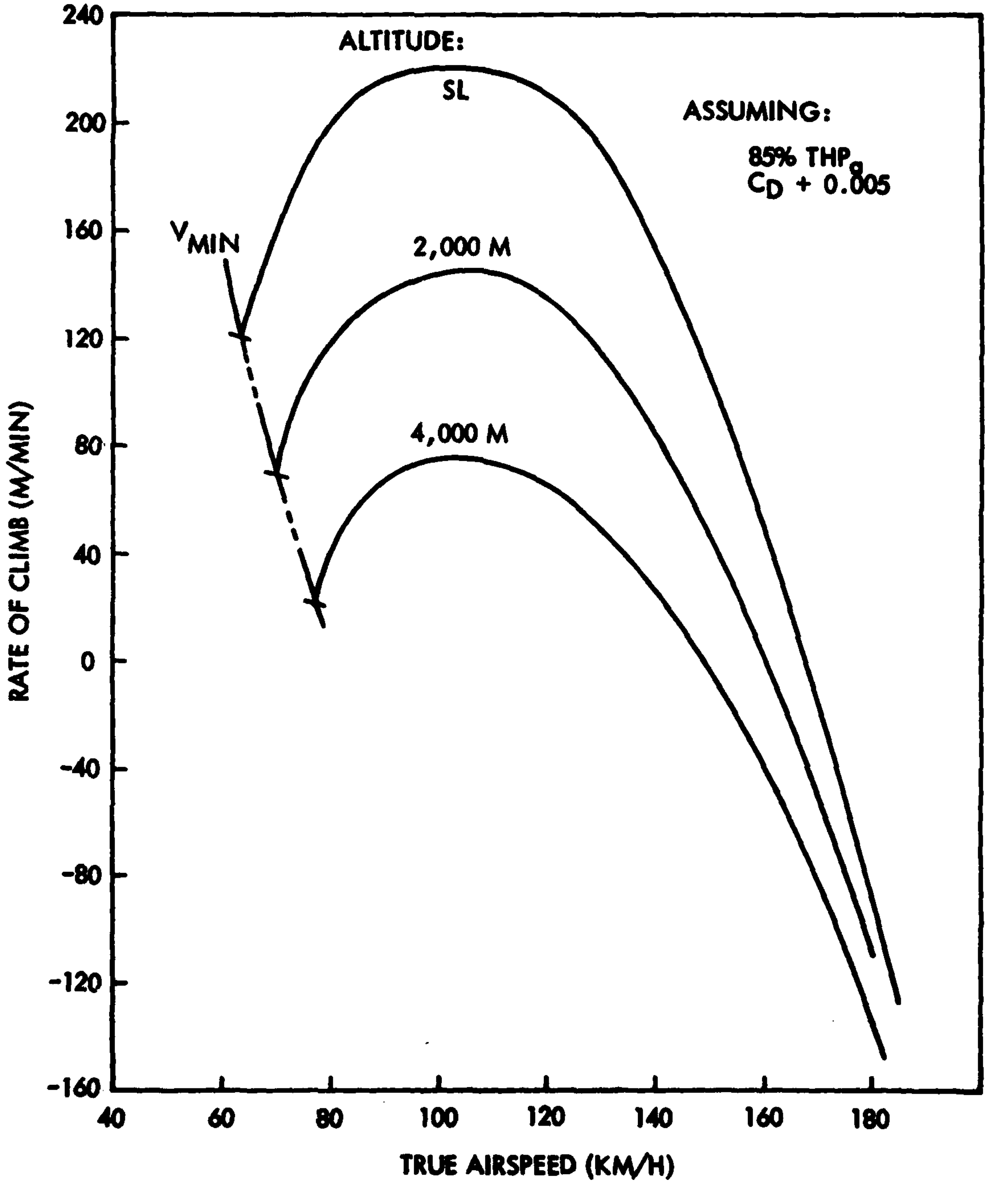


Figure D-13. Rate of Climb, 130 lb

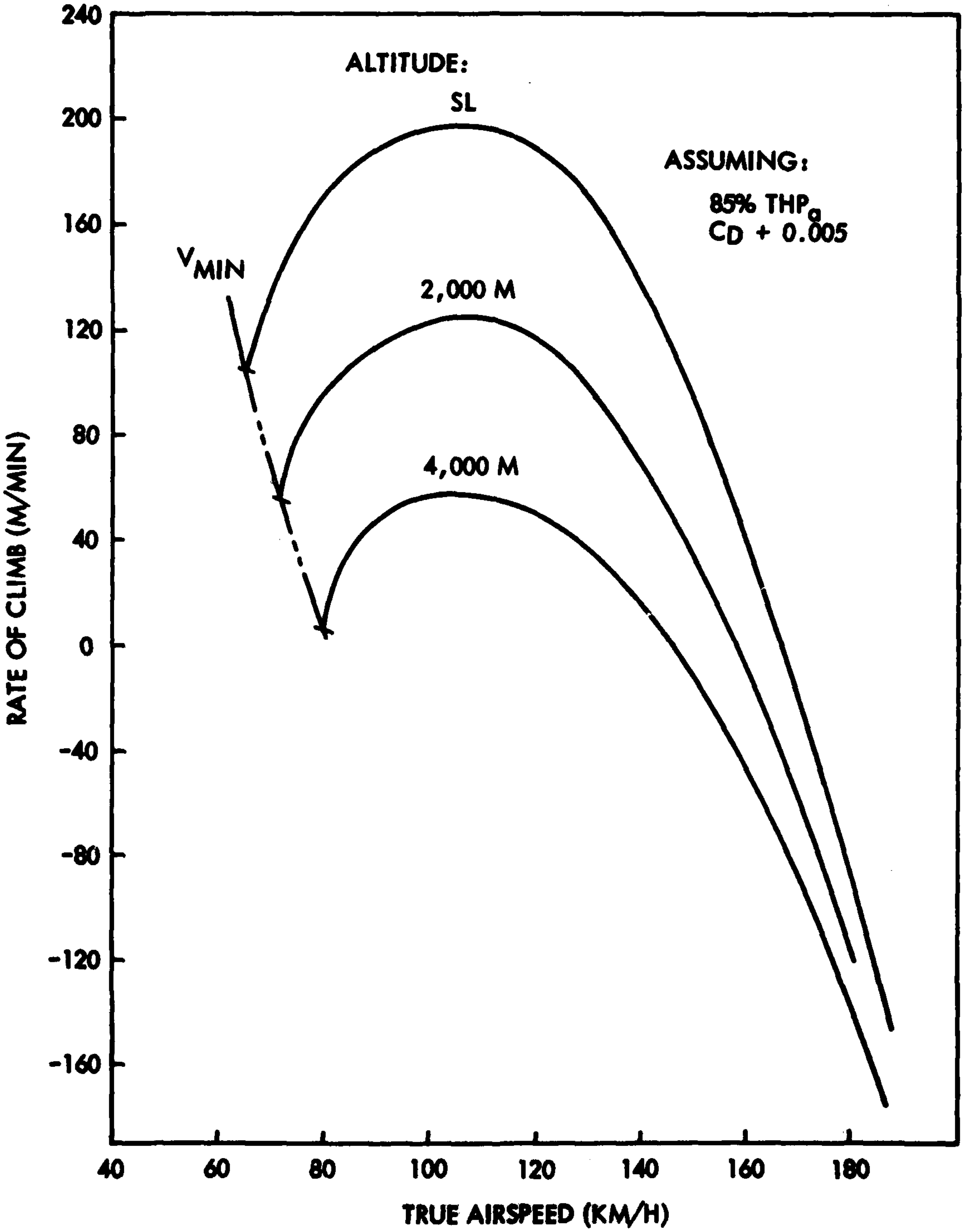


Figure D-14. Rate of Climb, 140 lb

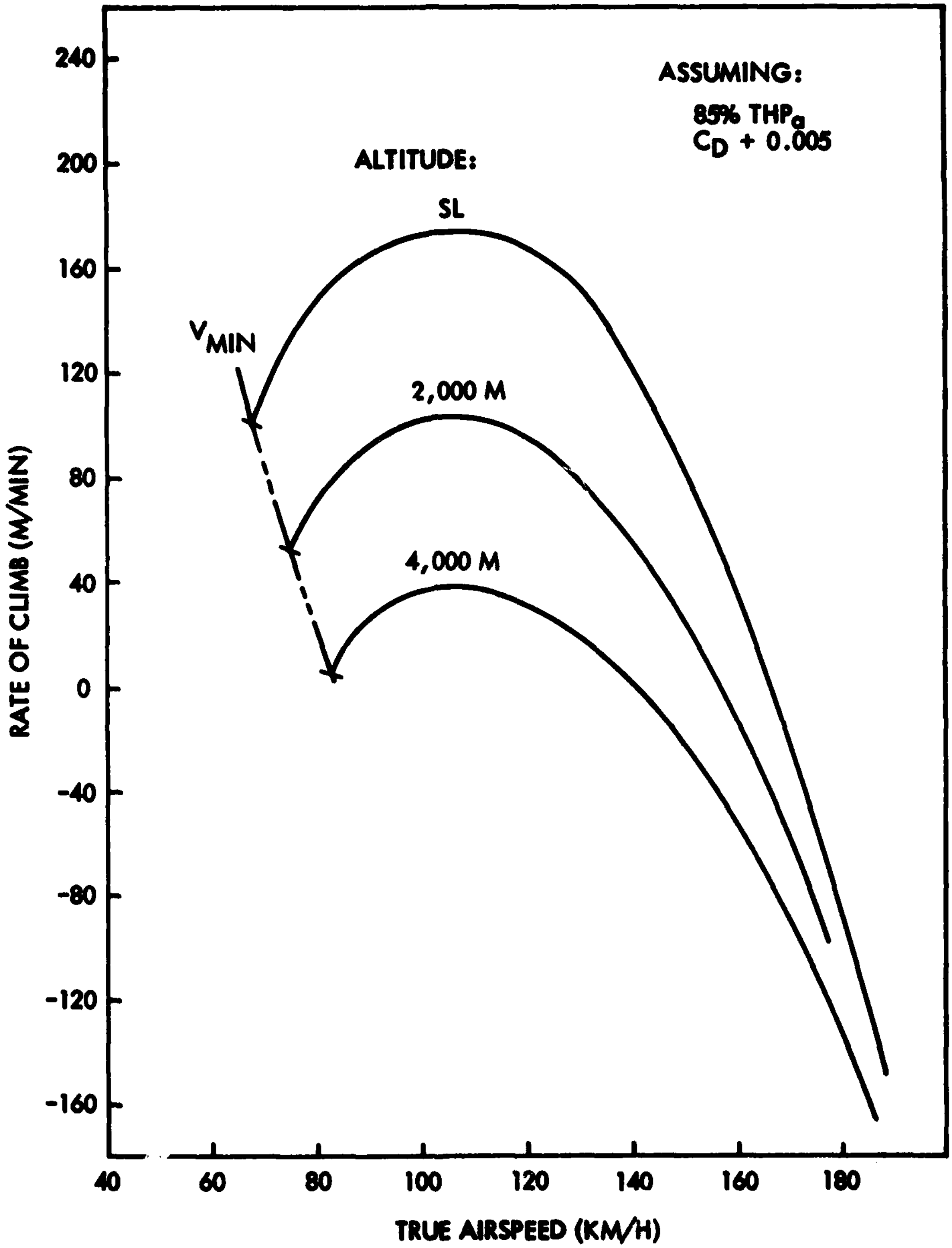
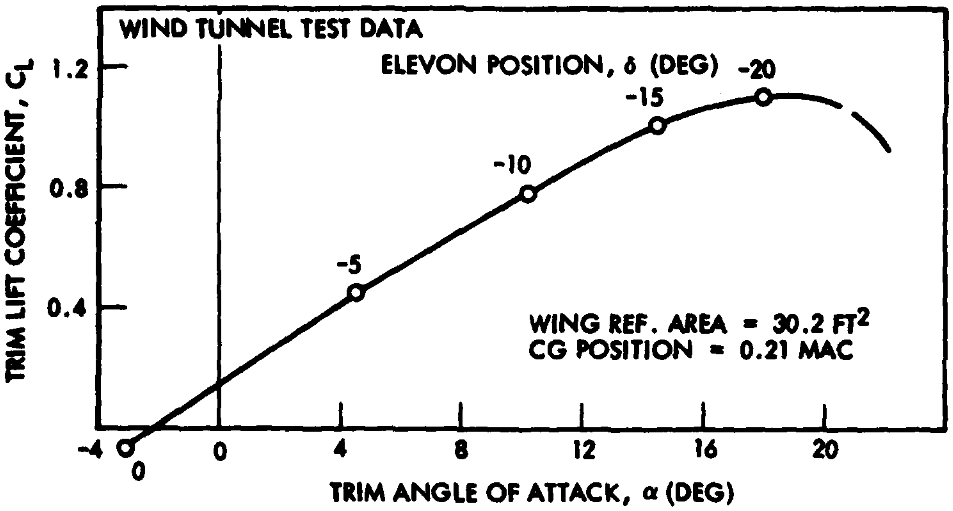


Figure D-15. Rate of Climb, 150 lb



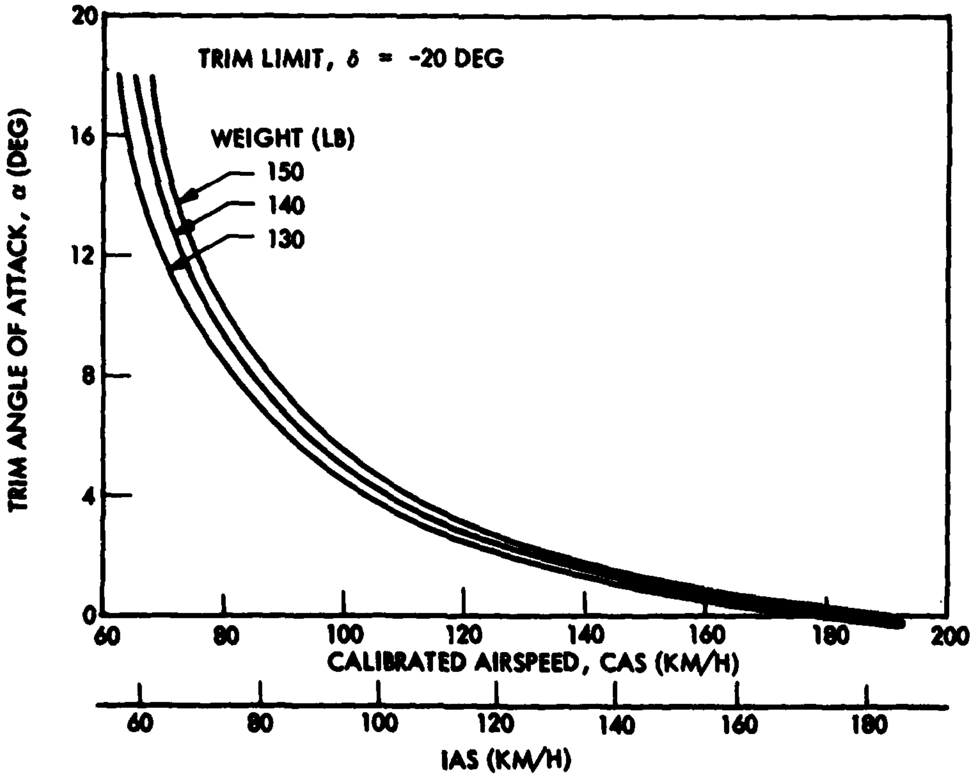


Figure D-16. Trim Angle of Attack and Lift Coefficient

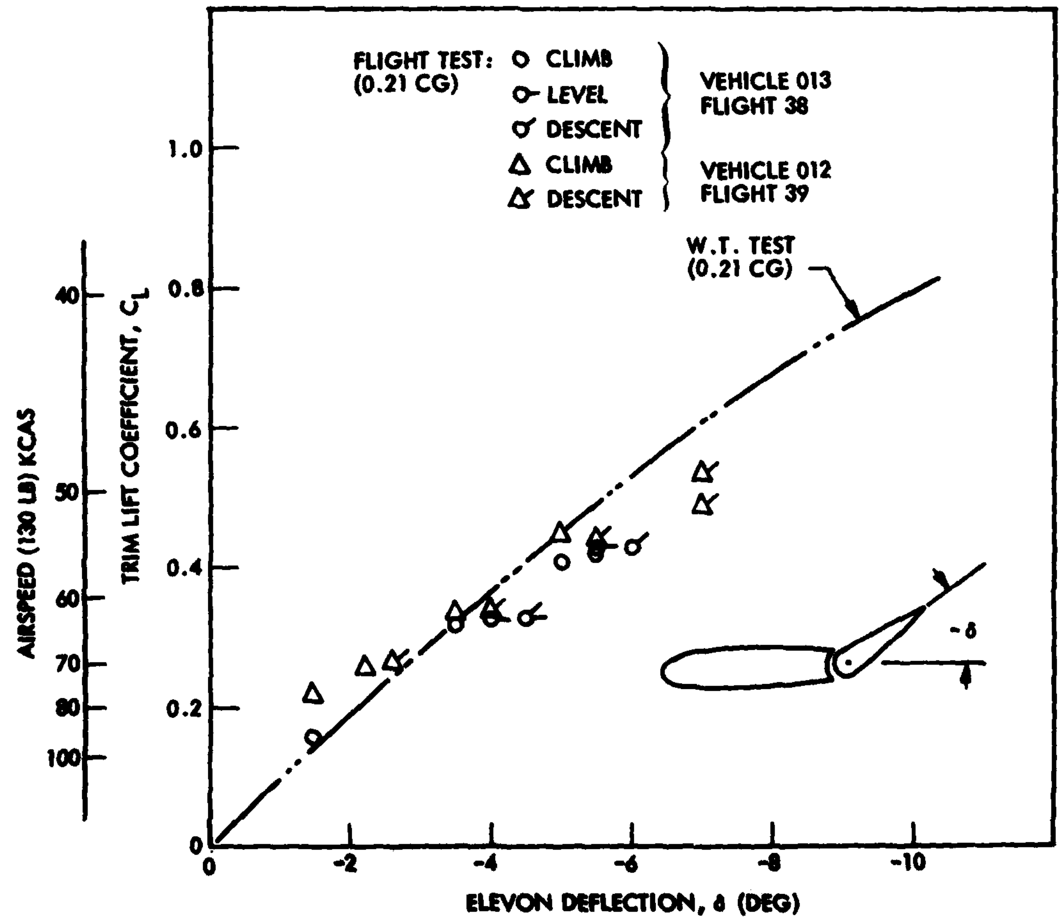


Figure D-17. Elevon Pitch Trim Angles

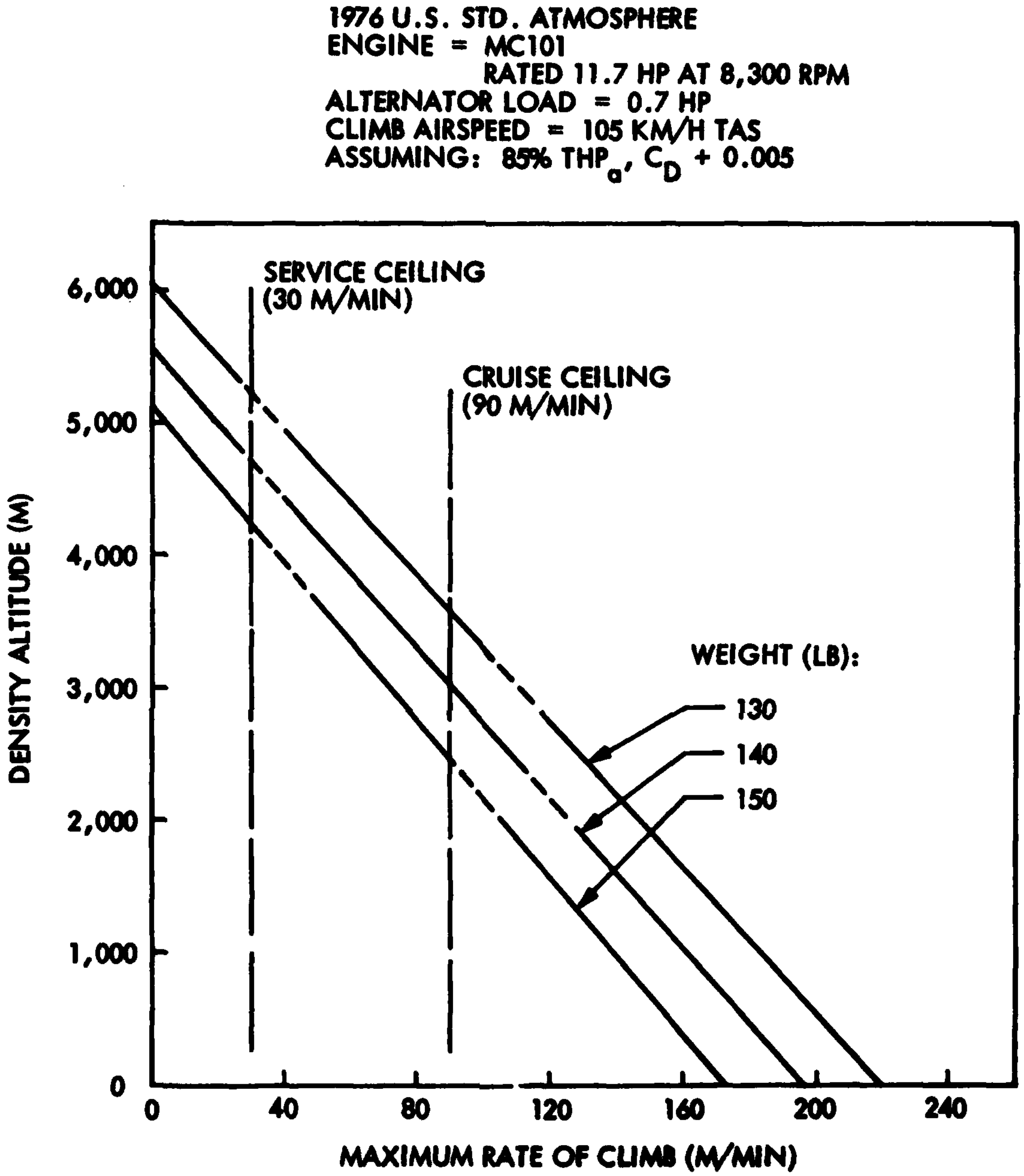


Figure D-18. Maximum Rate of Climb

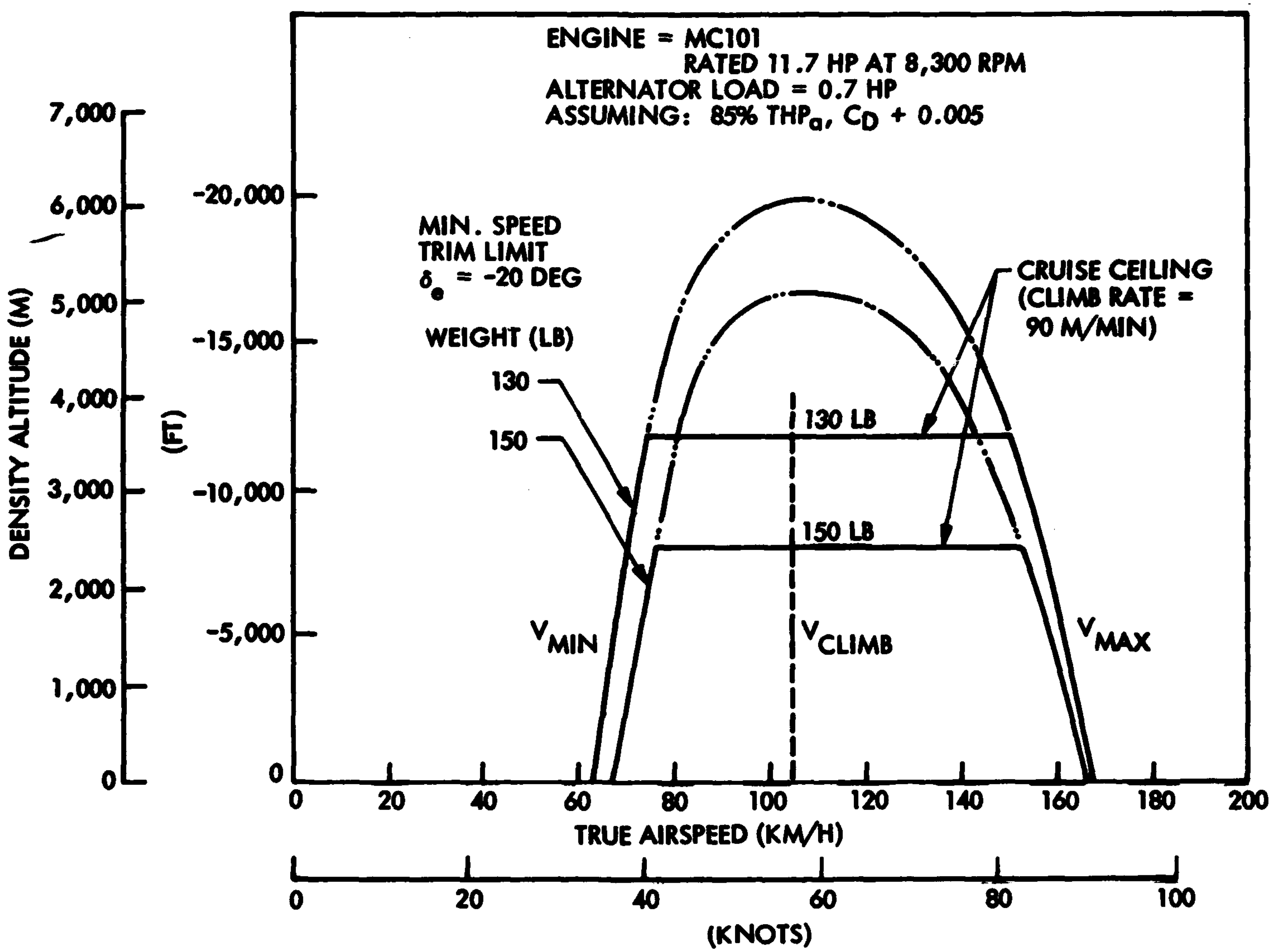


Figure D-19. Airspeed/Altitude Flight Envelope, TAS

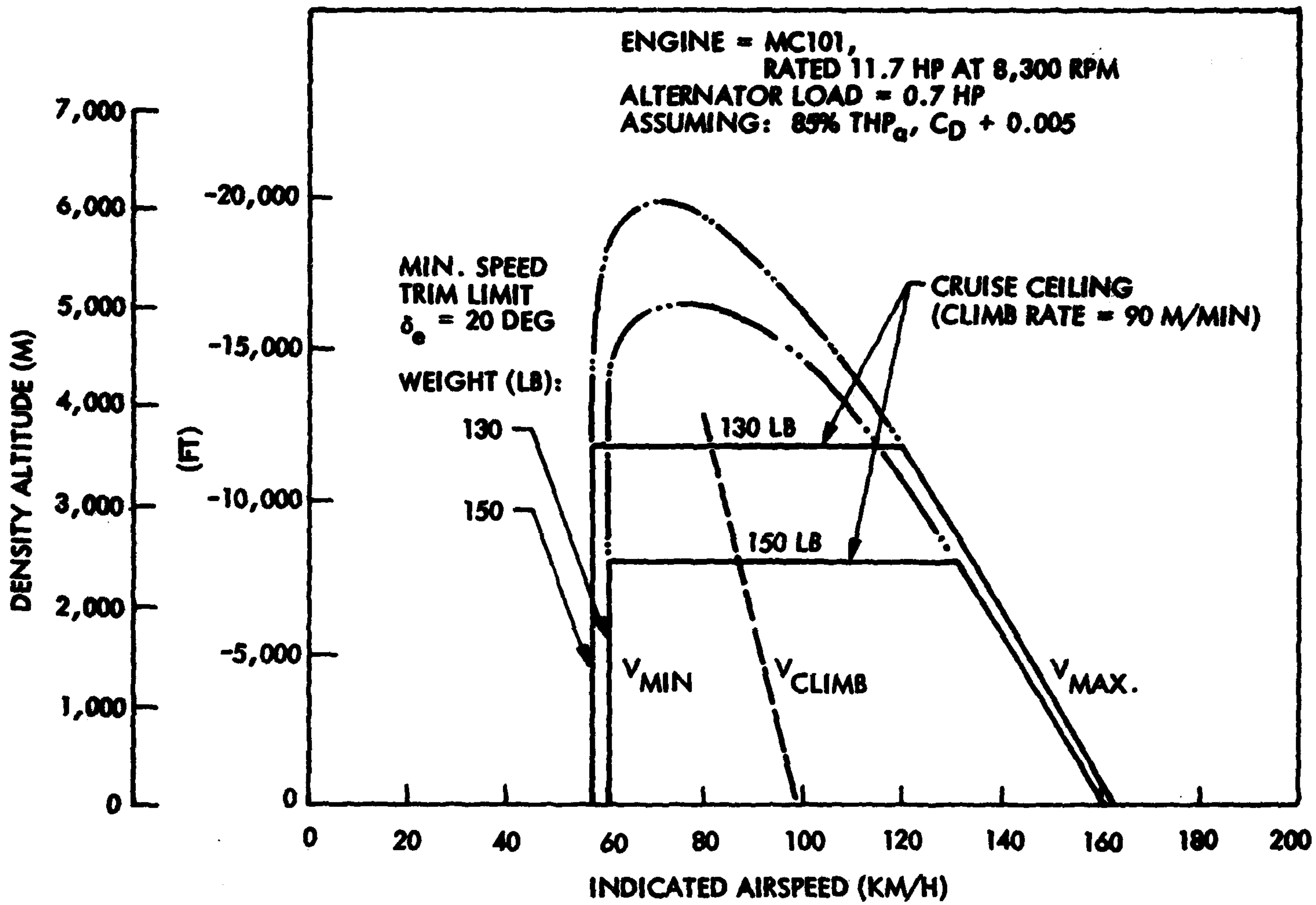


Figure D-20. Airspeed/Altitude Flight Envelope

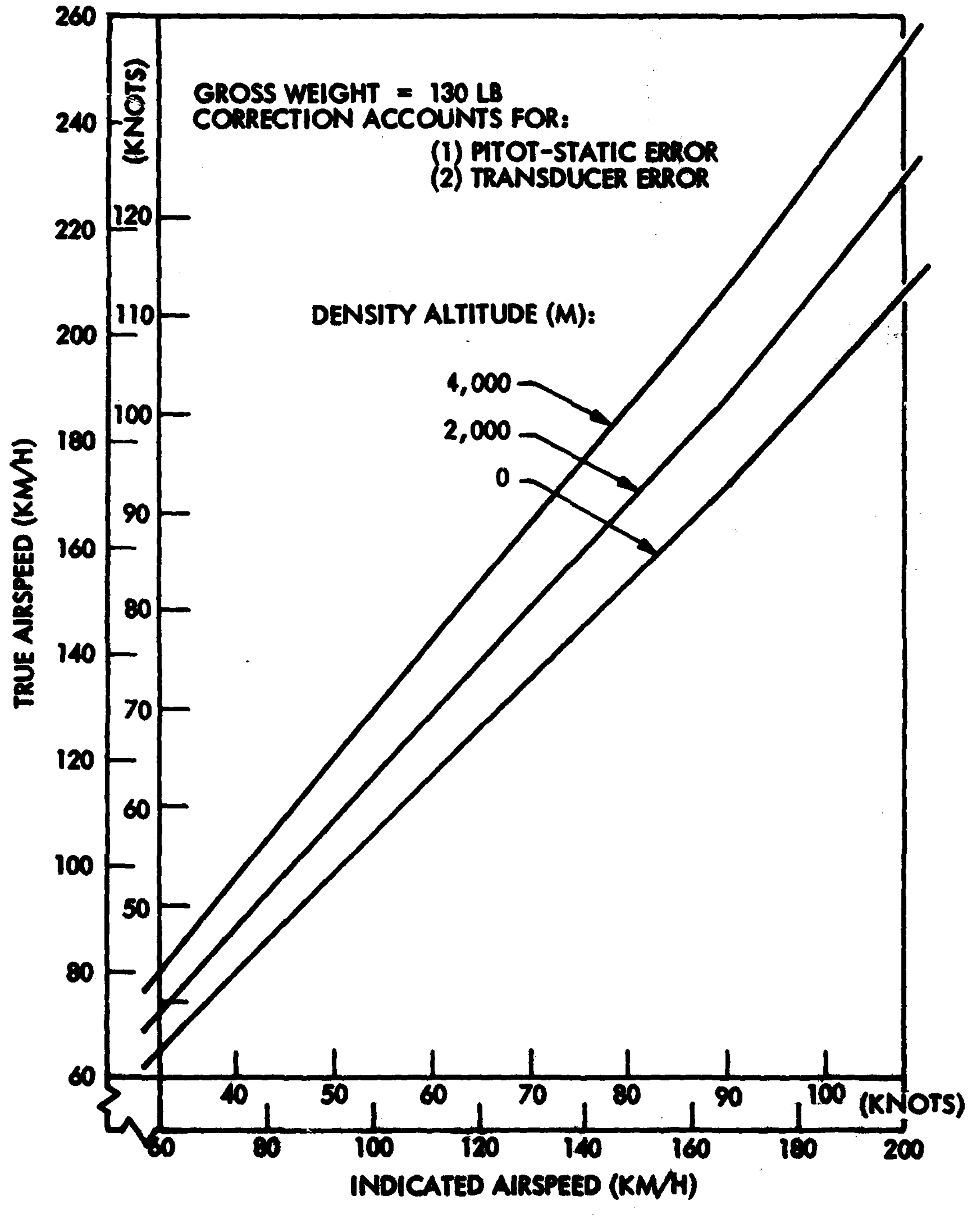


Figure D-21. True Airspeed Vs. Indicated Airspeed

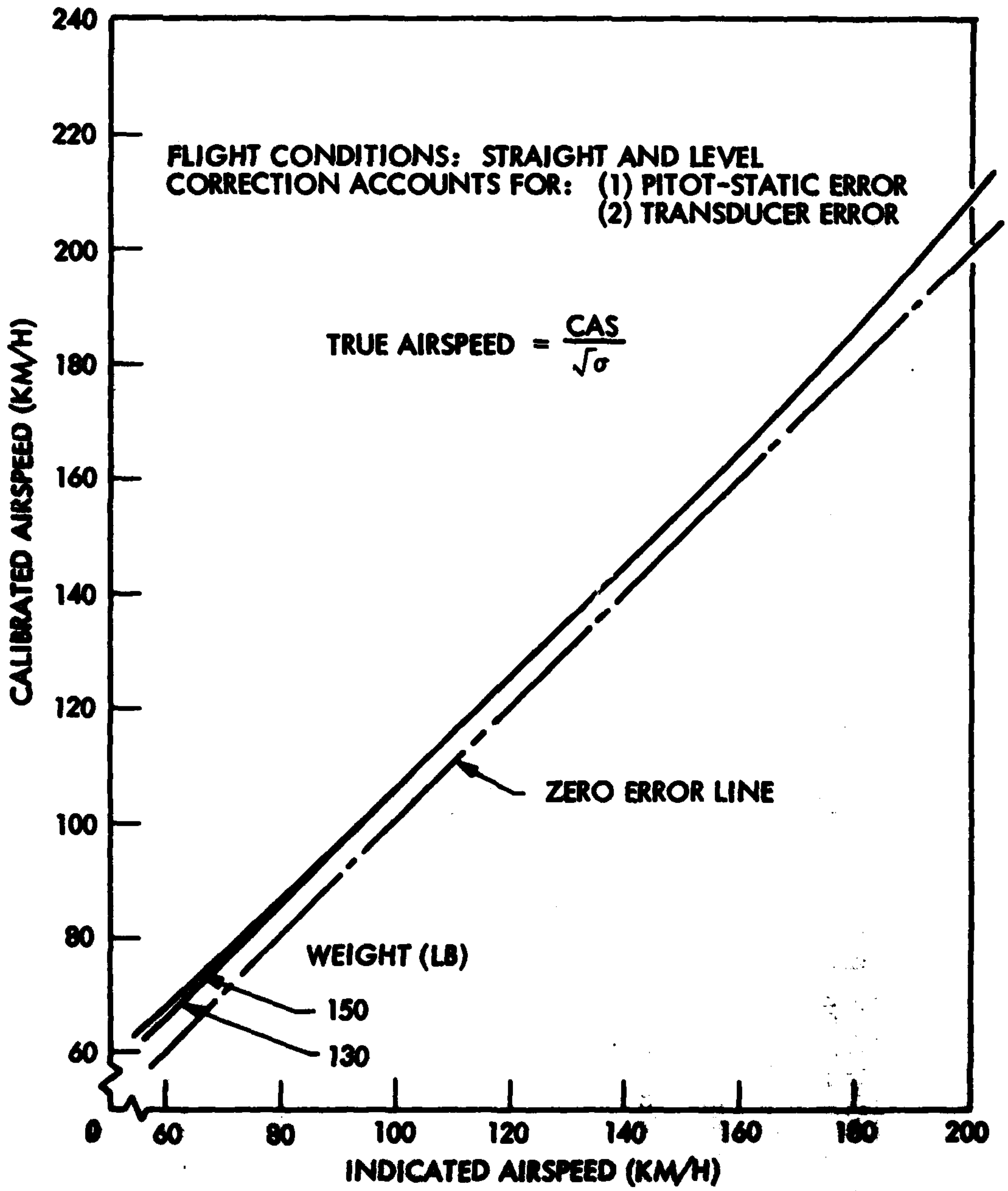


Figure D-22. Calibrated Airspeed

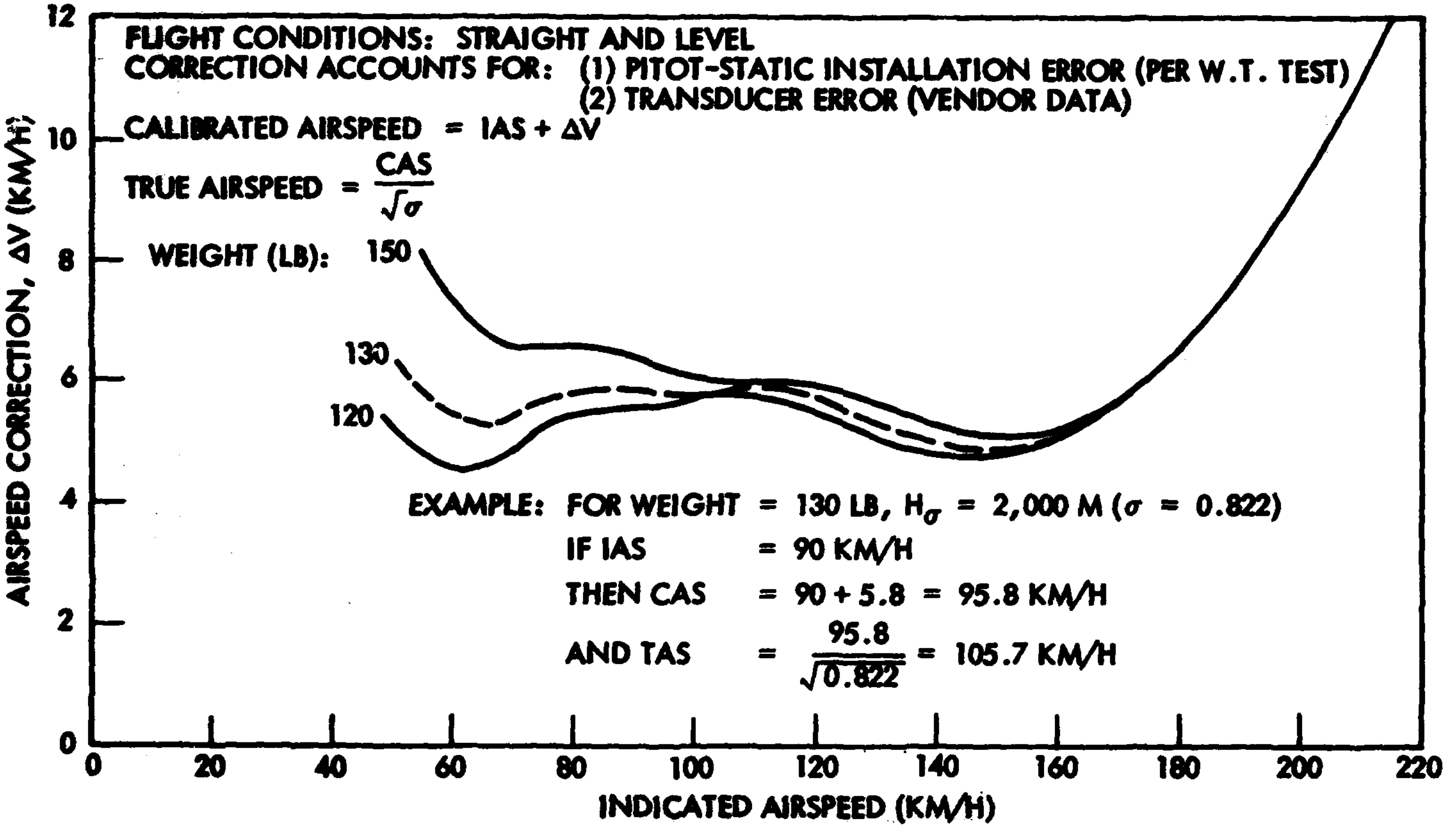


Figure D-23. Airspeed Correction

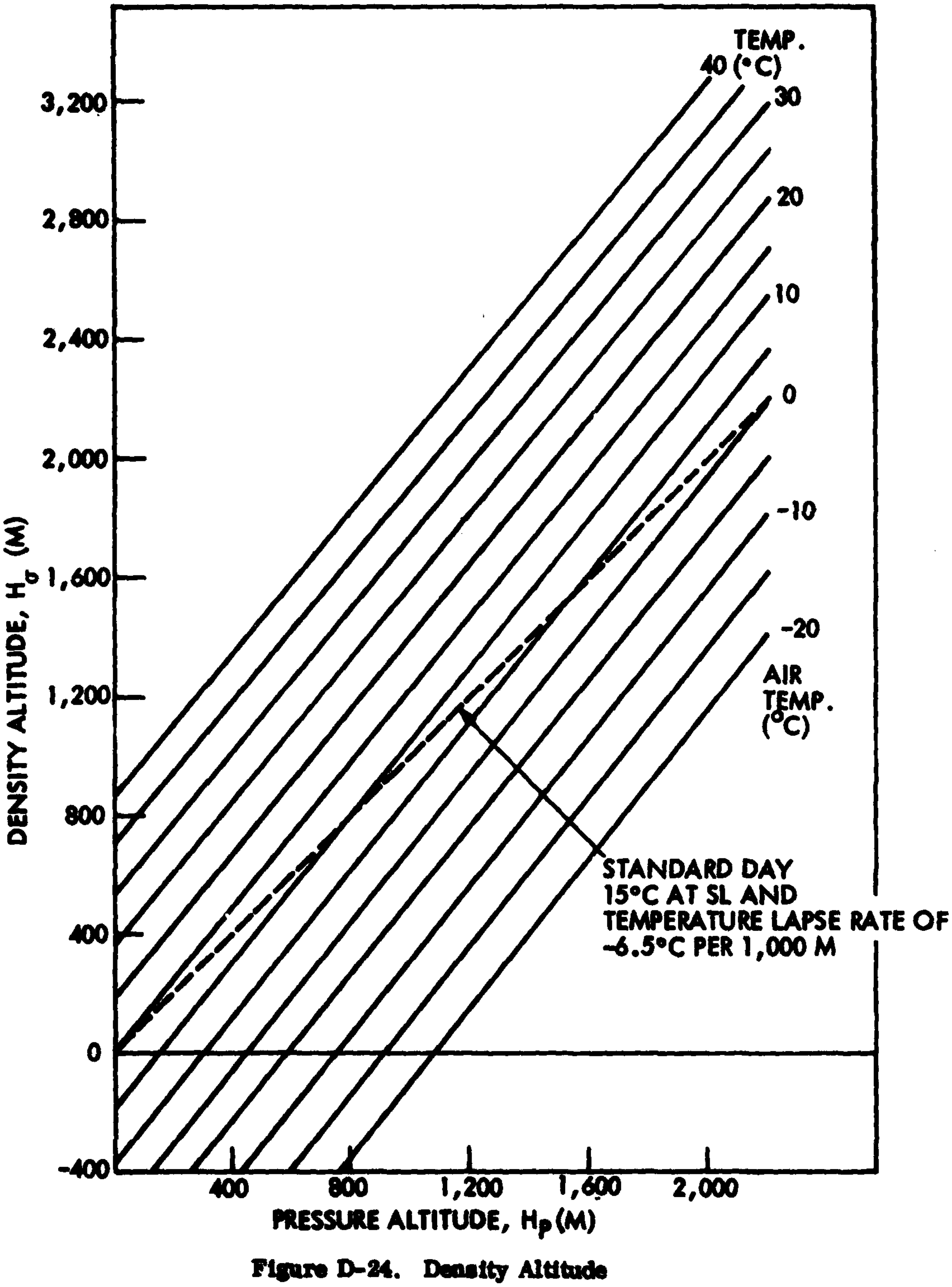


Figure D-24. Density Altitude

Appendix E
FLIGHT TEST LOG SHEETS

The enclosed log sheets show the data recorded and computed for all sensor flights. The missing flight numbers in the sequence from Flight 43 to Flight 65 are for Aquila aerodynamic performance flights in which a Sony camera was used in place of the sensor.

Only a few flights were used to obtain spatial resolution data, which have been computed in TV lines per picture height from the video tapes. All distance measurements are in meters. The ground error value in the target location measurements was calculated from the RSS value of the calculated northing and easting errors. It represents the ground distance between actual target location and calculated target location.

Table E-1

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 43

Flight Date 5-3-77 Launch Time 8:58 Flight Duration 1 hour 12 min

Flight No. 43 Sensor No. T-10 Software Version 39

RPV No. 14

Sensor Operator Stith Weather Calm

Test Objectives Phase I – Sensor Flight

Resolution Measurement

Time	9.08				
Sensor Downlook Angle	50				
Sensor Field of View					
Center Resolution – High Contrast	180 TVL				
– Low Contrast					

No. of Targets Attempted 5

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments

Very erratic – difficult to get good resolution – excessive image motion

Operator not familiar with range or target location – targets incorrectly cued

300 m tracking error

Table E-2

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 45

Flight Date 5-10-77 Launch Time 8:07 Flight Duration 1 hour 24 min

Flight No. 45 Sensor No. T-10 Software Version 41

RPV No. 14

Sensor Operator Stith Weather Wind

Test Objectives Phase I

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments

Target placement is questionable on this flight – targets incorrectly cued

Cannot use mechanical cage

Sensor erratic – excessive image motion

300 m tracking error

Table E-3

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 46

Flight Date 5-13-77 Launch Time 10:00 Flight Duration 1 hour 18 min.

Flight No. 46 Sensor No. T303 Software Version 42

RPV No. 15

Sensor Operator Stith Weather

Test Objectives Phase III

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments

Sensor locked in mechanical cage – no targeting data taken

Lost video – due to overheating of the silicon video tube (P/L-304) This resulted from the "out of mechanical cage command" issued.

Roll oscillation at 17 to 21 km range

TABLE E-4

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 47

Flight Date 5-14-77 Launch Time 7:00 Flight Duration 1 hour 32 min

Flight No. 47 Sensor No. T-10 + camera 01 Software Version 42

RPV No. 14

Sensor Operator Army Weather Calm

Test Objectives Phase I and II – Camera Performance Evaluation flight with a secondary objective of hands-on training for the Ft. Sill Army students.

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments

No targets detected on this flight – excess image motion

Three dead reckoning legs flown – deviated from planned pattern – manual re-establishment of link required

Phase II camera exercised

Table E-5

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 48

Flight Date 5-14-77 Launch Time 9:28 Flight Duration 36 min

Flight No. 48 Sensor No. T303 Software Version 42

RPV No. 15

Sensor Operator Webb Weather

Test Objectives Phase III Sensor – Check flight to verify Phase III sensor.

Mechanical cage pin fix was satisfactory.

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments Not Targeting Flight – Sensor Operator did lock on objects for practice.
Lots of distraction in GCS
Crash (flown into hill) – Operator error

Table E-6

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 49

Flight Date 5-19-77 Launch Time 7:36 Flight Duration 1 hour 53 min

Flight No. 49 Sensor No. T304 Software Version 42

RPV No. 14

Sensor Operator Stith Weather Calm

Test Objectives Phase III – Primary detection of road and field targets secondary: Army hands-on training.

Resolution Measurement

Time	7:46:15	7:46:52	8:01:17	8:01:17	8:14:19
Sensor Downlook Angle	70	35	70	70	40
Sensor Field of View	4 deg				
Center Resolution – High Contrast	210	205	195	250	175
– Low Contrast	H	V	H	V	H

No. of Targets Attempted 15

Detection

Target Type	Road	Field	Field	Field	Road
Target No.	48	Tank	Apex	110	48
RPV Easting	72059	73635		70889	67928
RPV Northing	96730	97998		95742	93994
Time	7:50:56	7:52:02	7:55:01	8:05:30	8:16:05
FOV	20 deg	20 deg		15 deg	AR
Range	2099	2515		1805	6969

Recognition

Target Type	Road	Field	Field	Field	Road
Target No.	48	Tank	Apex	110	48
RPV Easting	72599	74350	70499	72332	
RPV Northing	97115	98465	01016	96974	
Time	7:50:56	7:52:30	7:55:32	8:06:31	no lock
FOV	AR	AR	AR	AR	
Range	1490	1736	1502	835	

Comments

Sensor Control Handle Loose – AGL ≈ 700 m

LOS Angle off by 15 deg

H = Horizontal resolution measurement

V = Vertical resolution measurement

AR = FOV selected as required by operator – value not recorded

Table E-6 (Cont.)

Flight Date 5-19-77 Launch Time ________ Flight Duration ________

Flight No. 49 (Continued) Sensor No. ________ Software Version ________

RPV No. ________

Sensor Operator ________ Weather ________

Test Objectives ________

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ________

Detection

Target Type	Road	Field	Field	Road	Apex
Target No.	110	33	92	48	
RPV Easting	69944	72784	66647	69817	69458
RPV Northing	94164	97258	00947	95105	98374
Time	8:17:23	8:19:23	8:25:45	8:47:54	8:55:17
FOV	AR	AR	AR	AR	AR
Range	3445	3024	2470	2812	4383

Recognition

Target Type	Road	Field	Field	Road	Apex
Target No.	110	33	92	48	
RPV Easting	71327	73448		72123	
RPV Northing	96156	00371	no lock	96731	no lock
Time	8:18:22	8:21:34		8:49:32	
FOV	AR	AR		AR	
Range	1300	740		2048	

Comments Sensor Control handle loose – AGL ≈ 700 m
LOS Angle off by 15 deg

Table E-6 (Cont.)

Flight Date 5-19-77 Launch Time 7:36 Flight Duration 1 hour 53 min

Flight No. 49 (Continued) Sensor No. ______ Software Version ______

RPV No. ______

Sensor Operator ______ Weather ______

Test Objectives ______

Resolution Measurement

Time	8:44				
Sensor Downlook Angle	85				
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type	Road	Road	Field		
Target No.	48	110	Tank		
RPV Easting	72056	69025	74323		
RPV Northing	96667	94401	98397		
Time	9:02:10	8:59:58	9:03:40		
FOV	AR	AR	AR		
Range	2135	4012	1657		

Recognition

Target Type	Road	Road	Field		
Target No.	48	110	Tank		
RPV Easting	72327	70065	74147		
RPV Northing	96906	95221	99297		
Time	9:02:16	9:00:43	9:04:10		
FOV	AR	15	AR		
Range	1800	2728	1268		

Comments

Table E-7

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 50

Flight Date 5-23-77 Launch Time 7:14 Flight Duration 1 hour 59 min

Flight No. 50 Sensor No. T304 Software Version 42

RPV No. 14

Sensor Operator Stith/Webb Weather Calm

Test Objectives Phase III – Sensor Flight

Resolution Measurement

Time	7:52				
Sensor Downlook Angle	35 deg				
Sensor Field of View					
Center Resolution – High Contrast	180 TVL				
– Low Contrast	170 TVL				

No. of Targets Attempted 12

Detection

Target Type	Road	Field	Field	Road	Field
Target No.	48	Tank	92	110	33
RPV Easting	66742	74389	71001	70345	74098
RPV Northing	94081	98742	01012	95427	98209
Time	7:25:07	7:30:31	7:33:20	7:42:31	7:45:20
FOV	40 deg	AR	AR	AR	AR
Range	7938	1526	2149	2396	2155

Recognition

Target Type	Road	Field	Field	Road	Field
Target No.	48	Tank	92	110	33
RPV Easting	73066	74214	68874	71266	74430
RPV Northing	97483	99218	00970	96136	00404
Time	7:29:25	7:30:43	7:34:24	7:43:12	7:46:57
FOV	4 deg	AR	AR	AR	20 deg
Range	1008	1418	815	1354	751

Comments Shadows seemed to present some problems with identification of targets.

AGL ≈ 700 m

AR = FOV as required by operator – value not recorded

Table E-7 (Cont.)

Flight Date 5-23-77 Launch Time ______ Flight Duration ______
Flight No. 50 (Continued) Sensor No. ______ Software Version ______
RPV No.. 14
Sensor Operator ______ Weather ______
Test Objectives ______

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type		Field	Road	Field	
Target No.		92	48	Tank	
RPV Easting		71651	66885	73865	
RPV Northing		01041	94918	98097	
Time		8:12:45	8:35:30	8:40:20	
FOV		AR	AR	AR	
Range		2765	7487	2185	

Recognition

Target Type		Field	Road	Field	
Target No.		92	48	Tank	
RPV Easting		68817	72933	74398	
RPV Northing		00975	97372	98919	
Time		8:14:21	8:39:45	8:41:12	
FOV		AR	AR	AR	
Range		829	1137	1231	

Comments

Table E-7 (Cont.)

Flight Date 5-23-77 Launch Time 7:14 Flight Duration ______

Flight No. 50 (Continued) Sensor No. T304 Software Version ______

RPV No. 14

Sensor Operator ______ Weather ______

Test Objectives ______

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type	Road	Road	Field		
Target No.	110	48	73		
RPV Easting	69254	74765	66924		
RPV Northing	94674	98041	01051		
Time	8:49:30	8:52:42	8:58:30		
FOV	AR	AR	AR		
Range	3680	1287	3371		

Recognition

Target Type	Road	Road	Field		
Target No.	110	48	73		
RPV Easting	71931	74267	66347		
RPV Northing	96605	98289	00957		
Time	8:51:24	8:53:02	8:58:44		
FOV	AR	AR	AR		
Range	826	1008	3658		

Comments

Table E-8

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 54

Flight Date 6-12-77 Launch Time 9:33 Flight Duration 37 min

Flight No. 54 Sensor No. T502 Software Version 51

RPV No. 16

Sensor Operator Stith Weather

Test Objectives Phase IV Sensor – First YAG Flight

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments

Installed dome protection modification

Video sync. problems with sensor shortly after launch

Cannot get out of mechanical cage

No sensor data could be attempted – mission aborted – intermittent status link

Table E-9

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 55

Flight Date 6-12-77 Launch Time 14:28 Flight Duration 1 hour 06 min

Flight No. 55 Sensor No. T501 Software Version 51

RPV No. 16

Sensor Operator Stith Weather

Test Objectives Phase V

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments No target detection

Sensor dome found to have a cut after flight

Could not get out of mechanical cage

Table E-10

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 56

Flight Date 6-16-77 Launch Time ______ Flight Duration T-403

Flight No. 56 Sensor No. T403 Software Version 51

RPV No. 16

Sensor Operator ______ Weather ______

Test Objectives First YAG flight in RPV.

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments See laser designation/location sheets for results.

Table E-10 (Cont.)

Flight Date 6-16-77 Sensor No. T403

Flight Number 56 (Continued) Laser Type YAG

Laser Designation						
Target Type	Road	Road	Road	Road	Field	Field
Target No.	48	48	48	48	Tank	Tank
Time	17:11:10	17:12:42	17:13:37	17:14:45	17:16:13	17:18:45
Target on	Black	Black	Black	Black	Black	Black
RPV Northing	96046	97043	96819	97388	99071	99662
RPV Easting	71212	72702	71836	72546	74121	73876
RPV Altitude	700	700	700	700	800	800
Range (Voice)			2285	1515		
Range Computed	3143	1453	2236	1423	1596	1677
Target Location						
Actual Northing	97829	97829	97829	97829	99700	99700
Actual Easting	73705	73705	73705	73705	75350	75350
Actual Altitude	1289	1289	1289	1289	1280	1280
Measured Northing	97928	97883	97563	97486	99807	99661
Measured Easting	73699	73174	73922	73213	75478	75274
Measured Altitude	1201	1236	1252	1213	1144	1127
Northing Error	99	54	266	343	107	39
Easting Error	6	531	217	492	128	76
Altitude Error	88	53	37	76	136	153
Ground Error	100	533	343	599	166	85

Comments Came out of mechanical cage on this flight

Lost video at 17:22:25 after considerable blooming

Errors in altitude/range formulation determined (Software Version 51) – data invalid

Table E-11

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 57

Flight Date 6-17-77 Launch Time 9:36 Flight Duration 1 hour 58 min

Flight No. 57 Sensor No. T401 Software Version 51

RPV No. 16

Sensor Operator ______ Weather ______

Test Objectives YAG laser location and designation

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments See laser designation/location sheets for results.

Table E-11 (Cont.)

Flight Date 6-17-77 Sensor No. T401

Flight Number 57 (Continued) Laser Type Phase IV & V YAG Laser

Laser Designation						
Target Type	Road	Road	Road	Field	Apex	
Target No.	48	48	48	Tank		
Time	10:16:15	10:17:08	10:18:32	10:20:23	10:25:22	10:26:19
Target on	Black	Black	Black	Black	Black	Black
RPV Northing	95703	96722	96601	98545	01216	00638
RPV Easting	70763	72134	71893	74380	68288	68771
RPV Altitude	700	800	700	800	700	800
Range (Voice)						
Range Computed	3696	2081	2298	1707	2032	1073
Target Location						
Actual Northing	97829	97829	97829	99700	02701	02701
Actual Easting	73705	73705	73705	75350	69487	69487
Actual Altitude	1289	1289	1289	1280	1291	1291
Measured Northing	97944	97860	97764	04776	02347	05153
Measured Easting	73679	73713	73905	76665	69913	71423
Measured Altitude	1159	1215	1208	4169	1308	0078
Northing Error	115	31	65	5016	354	2452
Easting Error	26	8	200	1315	426	1936
Altitude Error	130	74	81	2889	17	1213
Ground Error	117	32	210	5185	553	3124

Comments

Errors in altitude/range formulation determined (Software Version 51) – data invalid

Range errors due to battery degradation

Table E-11 (Cont.)

Flight Date 6-17-77

Sensor No. T401

Flight Number 57 (Continued)

Laser Type Phase IV & V YAG Laser

Laser Designation						
Target Type	Apex	Apex				
Target No.						
Time	10:29:53	10:30:19				
Target on	Black	Black				
RPV Northing	00519	00821				
RPV Easting	68780	68256				
RPV Altitude	800	700				
Range (Voice)						
Range Computed	2429	1416				
Target Location						
Actual Northing	02701	02701				
Actual Easting	69487	69487				
Actual Altitude	1291	1291				
Measured Northing	02319	02246				
Measured Easting	69814	69925				
Measured Altitude	1206	1215				
Northing Error	382	455				
Easting Error	327	438				
Altitude Error	85	76				
Ground Error	502	681				

Comments

Table E-11 (Cont.)

Flight Date 6-17-77

Flight Number 57 (Continued)

Sensor No. T401

Laser Type YAG Laser

Laser Designation						
Target Type	Road	Road	Apex	Apex	Road	Field
Target No.	48	48			48	Tank
Time	10:43:39	10:46:40	11:01:57	11:02:12	11:10:07	11:12:47
Target on	Black	Black	Black	Black	Black	Black
RPV Northing	95775	96837	00909	00638	95391	98359
RPV Easting	70814	72511	69051	68793	70312	74315
RPV Altitude	800	700	700	700	700	800
Range (Voice)						
Range Computed	3635	1702	1972	2286	4236	1873
Target Location						
Actual Northing	97829	97829	02701	02701	97829	99700
Actual Easting	73706	73705	69487	69487	73705	75350
Actual Altitude	1289	1289	1291	1291	1289	1280
Measured Northing	97750	00918	08382	07386	97769	00241
Measured Easting	73798	78572	73110	74701	74964	74942
Measured Altitude	1084	4105	3037	3423	951	1131
Northing Error	79	3089	5681	4685	60	341
Easting Error	93	4867	3623	5214	1259	408
Altitude Error	205	2816	1746	2132	338	149
Ground Error	122	5764	6890	5633	1260	531

Comments

Errors in altitude/range formulation determined (Software Version 51) – data invalid

Table E-12

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 59

Flight Date 7-1-77 Launch Time 11:10 Flight Duration 54 min

Flight No. 59 Sensor No. ______ Software Version 51

RPV No. 16

Sensor Operator ______ Weather ______

Test Objectives ______

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments Locked in mechanical cage

Mission aborted

Table E-13
AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 61

Flight Date 7-7-77 Launch Time 9:20 Flight Duration 3 hours 28 sec
Flight No. 61 Sensor No. T-10 Software Version 54
RPV No. 14
Sensor Operator Army/Stith Weather
Test Objectives Phase I Sensor – Training Mission

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type	Road	Road	Road	Field	Field
Target No.	48	–	48	92	110
RPV Easting	71937	71059	73001	69251	71507
RPV Northing	96652	95738	97418	00990	96252
Time	9:34:50	9:47:49	10:01:05	10:06:13	10:15:07
FOV	20 deg	20 deg	U	12 deg	U
Range	2161	–	1074	846	1135

Recognition

Target Type			Road		
Target No.			48		
RPV Easting			74330		
RPV Northing			98312		
Time			10:02:07		
FOV			20 deg		
Range			938		

Comments
Excessive image motion due to RPV motion
Extensive blooming from the sensor on lower right-hand side
Sensor sync. erratic in this flight
Questionable target recognition
Good retrieval
Only data available for Phase I sensor in this series
U = FOV unknown

Table E-13 (Cont.)

Flight Date 7-7-77 Launch Time ______ Flight Duration ______
Flight No. 61 (Continued) Sensor No. ______ Software Version ______
RPV No. ______
Sensor Operator ______ Weather ______
Test Objectives ______

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type	Road	Apex			
Target No.					
RPV Easting	71423	70748			
RPV Northing	96197	01048			
Time	10:45:18	11:06:17			
FOV	18 deg	U			
Range		2193			

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments

Table E-14

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 62

Flight Date 7-7-77 Launch Time 13:48 Flight Duration 2 hours 17 min
Flight No. 62 Sensor No. T-401 Software Version 54
RPV No. 16
Sensor Operator Army/Stith (Advising) Weather
Test Objectives Phase IV, V, YAG Laser

Resolution Measurement

	Horz.	Vert.			
Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted 21

Detection

Target Type	Road	Road	Field	Road	Field
Target No.	48	48	Tank	48	Tank
RPV Easting	70725	71071	73071	70956	74217
RPV Northing	95697	96013	97446	95866	98728
Time	14:02:41	14:21:38	14:23:08	14:39:57	14:42:35
FOV	20 deg	12 deg	U	U	U
Range	3730	3275	3280	3449	1648

Recognition

Target Type	Road	Road	Field	Road	Field
Target No.	48	48	Tank	48	Tank
RPV Easting	74395	72262	74098	73167	74066
RPV Northing	98376	96856	98320	97634	99257
Time	14:05:34	14:22:31	14:23:57	14:41:40	14:42:55
FOV	U	12 deg	U	U	U
Range	1124	1875	1990	904	1462

Comments

Came out of mechanical cage and functioned well – some jitter in camera

Target data invalid – suspected magnetometer calibration errors and laser range errors – laser reading fixed at 5,320 m for several cases

Table E-14 (Cont.)

Flight Date 7-7-77

Flight Number 62 (Continued)

Sensor No. T401

Laser Type YAG Laser

Laser Designation						
Target Type	Pole	Pole	Field	Pole	Pole	Pole
Target No.	33	33	Tank	33	33	33
Time	14:11:51	14:13:07	14:23:57	14:29:58	14:30:37	14:48:09
Target on	Black	Black	Black	White	White	Black
RPV Northing	00411	01275	98320	01105	00657	01566
RPV Easting	67983	68277	74098	68317	67553	67907
RPV Altitude	700	800	700	700	700	800
Range (Voice)	5320	5320	5320	5320		
Range Computed	2674	1992	1990	2008	2853	2199
Target Location						
Actual Northing	02182	02182	99700	02182	02182	02182
Actual Easting	69861	69861	75350	69861	69861	69861
Actual Altitude	1291	1291	1280	1291	1291	1291
Measured Northing	03715	03834	02406	04033	03449	02463
Measured Easting	71942	72405	76785	72345	71959	69792
Measured Altitude	684	5475	131	0053	766	1299
Northing Error	1533	1652	2706	1851	1267	281
Easting Error	2081	2544	1435	2484	2098	69
Altitude Error	607	4184	1149	1238	525	8
Ground Error	2584	3033	3062	3097	2450	289

Comments

Tracking better black than white!

Table E-14 (Cont.)

Flight Date 7-7-77 — Sensor No. T401

Flight Number 62 (Continued) — Laser Type YAG

Laser Designation						
Target Type	Road	Road	Pole	Pole	Pole	Pole
Target No.	48	48	33	33	33	33
Time	15:00:50	15:01:18	15:14:57	15:18:11	15:35:11	15:37:18
Target on	Black	Black	Black	Black	Black	Black
RPV Northing	96798	97127	01271	00837	01184	01488
RPV Easting	73093	72607	67413	67270	67525	67928
RPV Altitude	700	800	700	800	700	800
Range (Voice)					2685	
Range Computed	1388	1361	2704	3026	2634	2204
Target Location						
Actual Northing	97829	97829	02182	02182	02182	02182
Actual Easting	73705	73705	69861	69861	69861	69861
Actual Altitude	1289	1289	1291	1291	1291	1291
Measured Northing	97846	97734	02530	04666	02404	02566
Measured Easting	73822	73799	69775	73920	69824	69848
Measured Altitude	1229	1189	1350	294	1377	
Northing Error	17	95	348	2484	222	384
Easting Error	117	94	86	4059	37	13
Altitude Error	60	100	59	997	86	
Ground Error	118	133	358	4758	225	384

Comments

Moisture seemed to appear on dome at 5:14.

Table E-14 (Cont.)

Flight Date 7-7-77

Flight Number 62 (Continued)

Sensor No. T401

Laser Type YAG

Laser Designation						
Target Type	Road	Road				
Target No.	48	48				
Time	15:47:15	15:47:33				
Target on	Black	Black				
RPV Northing	97439	97881				
RPV Easting	73194	73643				
RPV Altitude	800	700				
Range (Voice)	5320					
Range Computed	1026	704				
Target Location						
Actual Northing	97829	97829				
Actual Easting	73705	73705				
Actual Altitude	1289	1289				
Measured Northing	97874	97949				
Measured Easting	73689	73718				
Measured Altitude	1241	1198				
Northing Error	45	120				
Easting Error	16	13				
Altitude Error	48	91				
Ground Error	47	120				

Comments

Table E-14 (Cont.)

Flight Date 7-7-77

Flight Number 62 (Continued)

Sensor No. T401

Laser Type YAG

Laser Designation						
Target Type	Pole	Road				
Target No.	33	48				
Time	14:50:25	14:59:48				
Target on	Black	Black				
RPV Northing	00937	97089				
RPV Easting	68365	72583				
RPV Altitude	700	800				
Range (Voice)	2150					
Range Computed	2068	1555				
Target Location						
Actual Northing	02182	97829				
Actual Easting	69861	73705				
Actual Altitude	1291	1289				
Measured Northing	02152	97976				
Measured Easting	69947	73656				
Measured Altitude	1215	1226				
Northing Error	30	147				
Easting Error	86	49				
Altitude Error	76	63				
Ground Error	91	154				

Comments

Table E-15

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 63

Flight Date 7-8-77 Launch Time 10:37 Flight Duration 1 hour 26 min

Flight No. 63 Sensor No. 504 Software Version B54

RPV No. 017

Sensor Operator Army – Joann Weather

Test Objectives Phase III Eye Safe

Resolution Measurement

Time	V-10:48:20	H-10:49:45		V-10:49:11	H-10:49:23
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type	Road				
Target No.	48				
RPV Easting	73689				
RPV Northing	97799				
Time	10:54:43				
FOV					
Range	800				

Recognition

Target Type					
Target No.					
RPV Easting					
RPV Northing					
Time					
FOV					
Range					

Comments Sensor problems – Cage could be locked in down position.

Table E-16

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 64

Flight Date 7-9-77 Launch Time 10:18 Flight Duration 1 hour 19 min

Flight No. 64 Sensor No. T-504 Software Version 55

RPV No. 17

Sensor Operator Army Weather

Test Objectives Eye Safe Laser – Phase V

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted

Detection

Target Type	Field	Field			
Target No.	U	U			
RPV Easting	55866	56447			
RPV Northing	93012	95995			
Time	10:29:36	10:36:40			
FOV	U	U			
Range					

Recognition

Target Type	Field	Field			
Target No.	U	U			
RPV Easting	57966	55772			
RPV Northing	92992	96491			
Time	10:31:06	10:37:28			
FOV	U	U			
Range					

Comments Airspeed went down during some loiters.
Stall indicator flashed on screen.
Auto-Track was not working – manual track was used.
Data was invalid for YAG evaluation.

Table E-16 (Cont.)

Flight Date 7-9-77

Flight Number 64 (Continued)

Sensor No. T504

Laser Type Eye Safe

Laser Designation

Target Type	Field					
Target No.	Truck	Rat	Rat	Rat	Rat	Rat
Time	10:37:53	10:47:19	10:48:29	11:05:40	11:06:16	11:07:13
Target on	Black	Black	Black	Black	Black	Black
RPV Northing	96696	93010	93007	92978	93006	92995
RPV Easting	56496	55463	56787	56097	57031	58567
RPV Altitude		200	200	200	200	200
Range (Voice)					1100	
Range Computed		2594	1278	1963	1038	554

Target Location

Actual Northing		93017	93017	93017	93017	93017
Actual Easting		58050	58050	58050	58050	58050
Actual Altitude		1486	1486	1486	1486	1486
Measured Northing	96338	93172	93010	93124	93077	93017
Measured Easting	56007	58053	58051	58047	58044	58060
Measured Altitude	1448	1454	1452	1461	1477	1502
Northing Error		155	7	107	60	0
Easting Error		3	1	3	6	10
Altitude Error		32	34	25	9	16
Ground Error		155	7	107	60	10

Comments

Table E-16 (Cont.)

Flight Date 7-9-77

Sensor No. T504

Flight Number 64 (Continued)

Laser Type Eye Safe

Laser Designation	Reel 22					
Target Type						
Target No.	Rat	Rat	Rat	Rat	Rat	Rat
Time	11:15:18	11:15:47	11:23:53	11:24:38	11:27:34	11:28:05
Target on	Black	Black	Black	Black	Black	Black
RPV Northing	95995	95878	93013	92812	93047	93934
RPV Easting	56638	55760	55742	58476	58767	58863
RPV Altitude	200	300	200	300	200	200
Range (Voice)						
Range Computed	3301	3681	2316	1615	744	1241
Target Location						
Actual Northing	93017	93017	93017	93017	93017	93017
Actual Easting	58050	58050	58050	58050	58050	58050
Actual Altitude	1486	1486	1486	1486	1486	1486
Measured Northing	96599	96318	93247	92962	92982	92320
Measured Easting	54653	56000	60434	58062	58063	57514
Measured Altitude	926	1434	1161	1470	1484	1301
Northing Error	3582	3301	230	55	35	697
Easting Error	3397	2050	2384	12	13	536
Altitude Error	560	52	325	16	2	185
Ground Error	4936	3885	2395	56	37	879

Comments

Table E-16 (Cont.)

Flight Date 7-9-77

Flight Number 64 (Continued)

Sensor No. T504

Laser Type Eye Safe

Laser Designation						
Target Type						
Target No.	PAT	PAT				
Time	11:32:06	11:32:55				
Target on	Black	Black				
RPV Northing	96549	95831				
RPV Easting	56528	55849				
RPV Altitude	200	200				
Range (Voice)						
Range Computed	603	568				
Target Location						
Actual Northing	96343	96343				
Actual Easting	55997	55997				
Actual Altitude	1443	1443				
Measured Northing	96327	98990				
Measured Easting	56012	56485				
Measured Altitude	1447	159				
Northing Error	16	2647				
Easting Error	15	488				
Altitude Error	4	1284				
Ground Error	22	2691				

Comments

Table E-17

AQUILA FLIGHT TEST-SENSOR DATA LOG, FLIGHT 65

Flight Date 7-10-77 Launch Time 8:07 Flight Duration 3 hours

Flight No. 65 Sensor No. T502 Software Version 56

RPV No. 014

Sensor Operator Stith Weather Calm

Test Objectives YAG Laser – Phase V

Resolution Measurement

Time	8:15				
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast	240				
– Low Contrast	213 (edge)				

No. of Targets Attempted

Detection

Target Type	Road	Road	Road	Field	Road
Target No.	48	48	48	Tank	48
RPV Easting	70527	66825	67106	74296	67999
RPV Northing	95512	94002	94061	98535	93983
Time	8:21:25	8:36:49	8:54:53	8:59:56	10:11:34
FOV	20 deg	12 deg	AR	AR	AR
Range	4058	8014	7745	1762	6916
Above Alt. 2,800 AGL	1000	1500	1500	1500	700

Recognition

Target Type	Road	Road	Field	Road	Road
Target No.	48	48	Tank	48	48
RPV Easting	71743	72000	73701	73180	71062
RPV Northing	96534	96647	99702	97544	95938
Time	8:40:28	8:58:13	9:00:36	10:15:25	10:32:04
FOV	12 deg	AR	U	U	U
Range	2787	2560	1837	920	3323
AGL	1500	1500	1500	700	700

Comments

Table E-17 (Cont.)

Flight Date 7-10-77 Launch Time ______ Flight Duration ______

Flight No. 65 (Continued) Sensor No. ______ Software Version ______

RPV No. 014

Sensor Operator ______ Weather ______

Test Objectives ______

Resolution Measurement

Time					
Sensor Downlook Angle					
Sensor Field of View					
Center Resolution – High Contrast					
– Low Contrast					

No. of Targets Attempted ______

Detection

Target Type	Road				
Target No.	48				
RPV Easting	67895				
RPV Northing	94009				
Time	10:29:41				
FOV	U				
Range	6999				
AGL	700				

Recognition

Target Type	Road				
Target No.	48				
RPV Easting	71062				
RPV Northing	95938				
Time	10:32:04				
FOV	U				
Range	3323				
AGL	700				

Comments Auto-Track working well

Moisture on dome at 3,000 m

SMOOTH FLYING!

Table E-17 (Cont.)

Flight Date 7-10-77

Flight Number 65 (Continued)

Sensor No. T502

Laser Type YAG

Laser Designation						
Target Type	Pole	Field		Pole		Pole
Target No.	33	Tank		33		33
Time	8:29:19	8:42:06	8:42:33	8:46:50	8:47:56	9:04:03
Target on	Black					
RPV Northing	01563	98107	98634	01354	00544	01112
RPV Easting	67190	73894	74305	67654	67646	67788
RPV Altitude AGL	1500	700	700	1500	1500	1500
Range (Voice)	3035	2855				
Range Computed	3124	2268	1648	2793	3136	2772
Target Location						
Actual Northing	02182	99700	99700	02182	02182	02182
Actual Easting	69861	75350	75350	69861	69861	69861
Actual Altitude	1291	1280	1280	1291	1291	1291
Measured Northing	02577	99857	99848	02357	02199	02593
Measured Easting	70117	75171	75298	69900	69921	70451
Measured Altitude	1171	1195	1093	1290	1253	932
Northing Error	395	157	148	175	17	411
Easting Error	256	179	62	39	60	590
Altitude Error	120	85	190	1	38	359
Ground Error	470	238	160	179	63	719

Comments

Table E-17 (Cont.)

Flight Date 7-10-77

Flight Number 65 (Continued)

Sensor No. T502

Laser Type YAG

Laser Designation						
Target Type	Pole	Road	Road	Road	Pole	Pole
Target No.	33	48	48	48	33	33
Time	9:06:16	9:14:54	9:16:11	9:18:51	9:26:32	9:29:28
Target on	Black	Black	Black	Black	Black	Black
RPV Northing	01205	95690	97287	97494	01331	00472
RPV Easting	68275	70765	71754	72385	67574	67903
RPV Altitude	1500	1000	900	700	700	700
Range (Voice)			2235		2045	2790
Range Computed	2391	3770	2215	1531	2538	2692
Target Location						
Actual Northing	02182	97829	97829	97829	02182	02182
Actual Easting	69861	73705	73705	73705	69861	69861
Actual Altitude	1291	1289	1289	1289	1291	1291
Measured Northing	02246	97881	97922	97799	00386	02188
Measured Easting	69864	73651	73701	73724	69816	69895
Measured Altitude	1208	1213	1255	1264	1334	1236
Northing Error	64	52	93	30	1796	6
Easting Error	3	54	4	19	45	34
Altitude Error	83	76	34	25	43	55
Ground Error	64	75	93	35	1796	35

Comments

Table E-17 (Cont.)

Flight Date 7-10-77　　　　Sensor No. T502

Flight Number 65 (Continued)　　　　Laser Type YAG

Laser Designation						
Target Type	Pole	Pole	Pole	Pole		
Target No.	33	33	33	33		
Time	9:44:40	10:02:50	10:03:32	10:05:22		
Target on	Black	White	Black	Black		
RPV Northing	01301	01284	01050	00996		
RPV Easting	67495	67580	68419	68448		
RPV Altitude	700	700	700	700		
Range (Voice)						
Range Computed	2619	2549	1962	1973		
Target Location						
Actual Northing	02182	02182	02182	02182		
Actual Easting	69861	69861	69861	69861		
Actual Altitude	1291	1291	1291	1291		
Measured Northing	02700	02419	02195	02162		
Measured Easting	70482	69832	69867	69887		
Measured Altitude	1097	1326	1265	1259		
Northing Error	518	237	13	20		
Easting Error	621	29	6	26		
Altitude Error	194	35	26	32		
Ground Error	808	238	14	32		

Comments

Table E-17 (Cont.)

Flight Date 7-10-77

Flight Number 65 (Continued)

Sensor No. T502

Laser Type YAG

Laser Designation

Target Type	Pole	Pole	Pole	Field	Field	Pole
Target No.	33	33	33	Tank	Tank	33
Time	10:20:42	10:22:05	10:23:52	10:34:51	10:35:27	10:39:13
Target on	White	White	White	Black	Black	Black
RPV Northing	01080	00591	00543	98794	99673	01085
RPV Easting	67822	68034	68076	74165	73758	67748
RPV Altitude	700	700	700	700	700	700
Range (Voice)	2460	2600	2540	1725	1750	
Range Computed	2421	2521	2522	1647	1739	2481

Target Location

Actual Northing	02182	02182	02182	99700	99700	02182
Actual Easting	69861	69861	69861	75350	75350	69861
Actual Altitude	1291	1291	1291	1280	1280	1291
Measured Northing	02307	02245	02176	99797	99822	02365
Measured Easting	69842	69874	69910	75345	75332	70338
Measured Altitude	1301	1255	1266	1201	1210	1180
Northing Error	125	63	6	97	122	183
Easting Error	19	13	49	5	18	477
Altitude Error	10	36	25	79	70	111
Ground Error	126	64	50	98	123	510

Comments

Table E-17 (Cont.)

Flight Date 7-10-77 Sensor No. T502

Flight Number 65 (Continued) Laser Type YAG

Laser Designation

Target Type	Pole	Pole	Pole	Pole		
Target No.	33	33	33	33		
Time	10:39:46	10:43:56	10:44:20	10:45:14		
Target on	Black	Black	Black	Black		
RPV Northing	01461	00511	00755	01266		
RPV Easting	68032	68117	67522	68371		
RPV Altitude	700	700	700	700		
Range (Voice)		2480	2880	1940		
Range Computed	1958	2514	2827	1883		

Target Location

Actual Northing	02182	02182	02182	02182		
Actual Easting	69861	69861	69861	69861		
Actual Altitude	1291	1291	1291	1291		
Measured Northing	02346	02120	02305	02280		
Measured Easting	69852	69881	69832	69828		
Measured Altitude	1287	1247	1252	1245		
Northing Error	164	62	123	98		
Easting Error	9	20	29	33		
Altitude Error	4	44	39	46		
Ground Error	165	65	126	100		

Comments